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Identification and Management of Wildlife Damage

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Identification and Management of Wildlife Damage

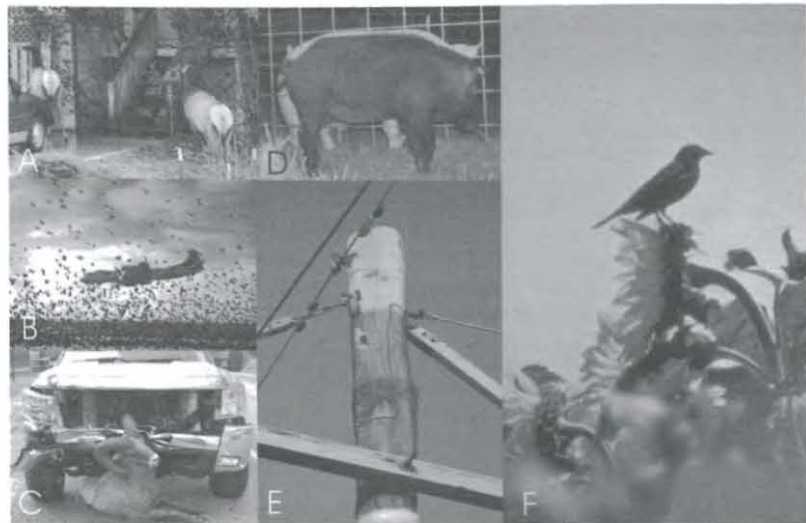
INTRODUCTION

WILDLIFE MANAGEMENT is often thought of in terms of protecting, enhancing, and nurturing wildlife populations and the habitat needed for their well-being. However, many species at one time or another require management actions to reduce **conflicts** with people, other wildlife species, or other resources. Examples include an airport manager modifying habitats to reduce gull (family Laridae) activity near runways, a forester poisoning pocket gophers (family Geomyidae) to increase tree seedling survival in a reforestation project, or a biologist trapping an abundant predator or competing species to enhance survival of an endangered species. These are just a few of many examples (e.g., Fig. 34.1).

Wildlife-damage management is an increasingly important part of the wildlife profession because of expanding human populations and intensified land-use practices. Wildlife damage in the United States approximates **\$22 billion** (hereafter, all currency given in U.S. dollars) in losses annually (Conover 2002). Concurrent with this growing need to reduce wildlife-people conflicts, public attitudes, and environmental regulations are restricting use of some of the traditional tools of control such as toxicants and traps. Agencies and individuals carrying out control programs are being scrutinized more carefully to ensure that their actions are justified, environmentally safe, humane, and in the public interest. Thus, wildlife-damage management activities must be based on sound economic, ecological, and sociological principles, and carried out as positive, necessary components of overall wildlife management programs.

Wildlife-damage management programs can be thought of as having 4 parts: (1) problem definition, (2) ecology of the problem species, (3) management methods application, and (4) evaluation of management effort. **Problem definition** refers to determining the species and numbers of animals causing the problem, the amount of loss or nature of the conflict, and other biological and social factors related to the problem. **Ecology** of the problem species refers to understanding the life history of the species, especially in relation to the conflict. Management methods **application** refers to taking the information gained from parts 1 and 2 to develop an appropriate management program to alleviate or reduce the conflict. **Evaluation** of management effort permits an assessment of the reduction in damage in relation to costs and impact of the management effort on target and nontarget populations. Emphasis is often placed on **integrated** wildlife-damage management, whereby several damage management methods are used in combination and coor-

Fig. 34.1. Examples of wildlife damage: (A) browsing ornamental plantings, (B) threats to aviation and human health, (C) wildlife-vehicle collisions, (D) disease transmission to livestock, (E) power-pole damage, and (F) crop damage. (A) Photo by K. VerCauteren; (B) photo by U.S. Animal and Plant Health Inspection Service, Wisconsin; (D) photo by C. Wyckoff; (E) photo by S. Tupper; (F) photo by U.S. Animal and Plant Health Inspection Service, Wisconsin.



minated with other management practices being used at that time.

This chapter focuses on techniques related to parts 1 (problem definition) and 3 (management methods application). Each major section on groups of wildlife species has 3 parts: (1) **assessment** of damage, (2) **identification** of damage by individual species, and (3) management **techniques**, which is an elaboration of those listed under each of the species.

LEGAL REQUIREMENTS FOR MANAGEMENT

Capturing or Killing Wildlife Species

Before action is taken to control or manage wildlife damage, it is important to understand the **laws** regarding both target and nontarget wildlife species. The management of most wild mammals, reptiles, and amphibians in the United States and Canada is the responsibility of the individual states and provinces. The capture, possession, or killing of these vertebrates to control damage or nuisance situations is regulated by state or provincial laws. The main exception for mammals, reptiles, and amphibians in the United States regards endangered species that are regulated federally by the Endangered Species Act of 1973, as amended.

Migratory birds, in contrast to other vertebrates, are managed in North America at the federal level under the **Migratory Bird Treaty Act** of 1918. The treaty has been amended several times to include formal agreements between the United States, Canada, Mexico, Japan, and Russia. Federal regulations in the United States and Canada require that a depredation permit be obtained from the U.S. Fish and Wildlife Service and Canadian Wildlife Service, respectively, before any person may capture, kill, possess, or transport most migratory birds to control depredations. No federal permit is required merely to frighten or herd depredating birds other than endangered or threatened species, and bald (*Haliaeetus leucocephalus*) or golden eagles (*Aquila chrysaetos*).

Birds in the Families Phasianidae (e.g., grouse spp., ptarmigan spp., wild turkey [*Meleagris gallopavo*]) and Odontophoridae (quail spp.) are considered **nonmigratory** and are regulated at the state and provincial level. Furthermore, birds **introduced** to the United States, such as house sparrows (*Passer domesticus*), pigeons (*Columba livia*), European starlings (*Sturnus vulgaris*), and monk parakeets (*Myiopsitta monachus*), have **no federal protection**. Furthermore, a federal permit is not required in the United States to control yellow-headed (*Xanthocephalus xanthocephalus*), red-winged (*Agelaius phoeniceus*), tri-colored (*A. tricolor*), rusty (*Euphagus carolinus*), and Brewer's blackbirds (*E. cyanocephalus*), or cowbirds (*Molothrus* spp.), all grackles (*Quiscalus* spp.), crows (*Corvus* spp.), and magpies (*Pica pica*), when they are committing or about to commit depredations upon ornamental or shade trees, agricultural crops, livestock, or wildlife, or when they are concentrated in such numbers and manner as to constitute a health hazard. However, federal provisions do not circumvent any state laws or regulations, which may be more, but not less, restrictive.

In summary, anyone contemplating the capture or killing of a vertebrate species for damage management must first determine the state or provincial regulations for that species. For most birds and all federally endangered species, federal regulations also must be followed.

Environmental Protection Agency

Registration of Chemicals

The **Federal Insecticide, Fungicide, and Rodenticide Act** (FIFRA), as amended, requires all pesticides and other chemicals used in controlling or repelling organisms in the United States to be approved and registered by the **Environmental Protection Agency** (EPA). The registration process is complex and costly, not only for new products, but also for previously registered products being reviewed and reevaluated (Goldman 1988). Products federally registered under Section

3 of FIFRA may not be available for use in all states, because many have their own registration requirements that might be more restrictive. Some products have Section 24C registrations that are valid only for specific states that have localized problems. Occasionally, products are available temporarily in specific localities for emergency use under Section 18 provisions of FIFRA. Finally, many of the registered compounds, such as vertebrate toxicants, are classified as **Restricted Use** pesticides. These products can only be used by, or under the direct supervision of, a certified pesticide applicator. Each state has its own certification requirements. Thus, anyone contemplating use of chemicals in wildlife-damage management must determine the status of, and requirements for use of, those chemicals in their particular locality. Jacobs (1994) provided a comprehensive list of registered chemicals for wildlife-damage management.

BIRD DAMAGE

Damage Assessment

Birds annually destroy many millions of dollars' worth of agricultural crops in North America. The greatest loss appears to be from **blackbirds** feeding on ripening corn (*Zea mays*); a survey in 1993 conservatively estimated a loss of 285,000 metric tons worth \$30 million in the United States (Wywiałowski 1996). Blackbird damage to sunflowers (*Helianthus* spp.) in the upper Great Plains states was estimated at \$8 million in 1980 (Hothem et al. 1988). Damage by various bird species, especially **European starlings**, to fruit crops such as cherries (*Prunus* spp.), grapes (*Vitis* spp.), and blueberries (*Vaccinium* spp.) can be severe in localized areas (Dolbeer et al. 1994a, Pimentel et al. 2000). **Fish-eating birds** can cause major losses at fish-rearing facilities and affect sport fishing (Gladin and Brugger 1995, Shwiff et al. 2008). Economic losses from bird strikes to aircraft are even more substan-

tial than losses to agriculture crops, with >\$600 million annually for U.S. civil aviation (Fig. 34.2; Dolbeer et al. 2009) and \$100 million for military aircraft (Conover et al. 1995).

Unlike most mammals, which are secretive when causing damage, birds are often highly visible and the damage is usually conspicuous. For these reasons, **subjective estimates** often overestimate losses as much as 10-fold (Weatherhead et al. 1982). Thus, **objective estimates** of bird damage to agricultural crops are important to accurately define the magnitude of the problem and to plan appropriate, cost-effective control actions (Dolbeer 1981).

To estimate losses to birds in agricultural crops, one must devise a sampling scheme to select the fields to be examined, and then determine the plants or areas to be measured in the selected fields (Stickley et al. 1979). For example, to objectively estimate the amount of blackbird damage in a ripening corn or sunflower field, the estimator should examine ≥ 10 locations randomly spaced in the field. If a field has 100 rows and is 300 m long, the estimator might walk staggered distances of 30 m along 10 randomly selected rows (e.g., 0–30 m in row 9, 31–60 m in row 20, etc.). In each 30-m length, the estimator should randomly select 10 plants and estimate the damage on each plant's ear or head. Bird damage to corn can be estimated by measuring the length of damage on the ear (De Grazio et al. 1969) or by visually estimating the percent loss of kernels (Woronecki et al. 1980) and converting to yield loss per hectare. Fruit loss can be estimated by counting the numbers of undamaged, pecked, and removed fruits per sampled branch (Tobin and Dolbeer 1987). Sprouting rice (*Oryza sativa*) removed by birds can be estimated by comparing plant density in exposed plots to that in adjacent plots with wire bird enclosures (Otis et al. 1983). The seeded surface area of sunflower heads destroyed by birds can be estimated with the aid of a plastic template (Fig. 34.3; Dolbeer 1975).

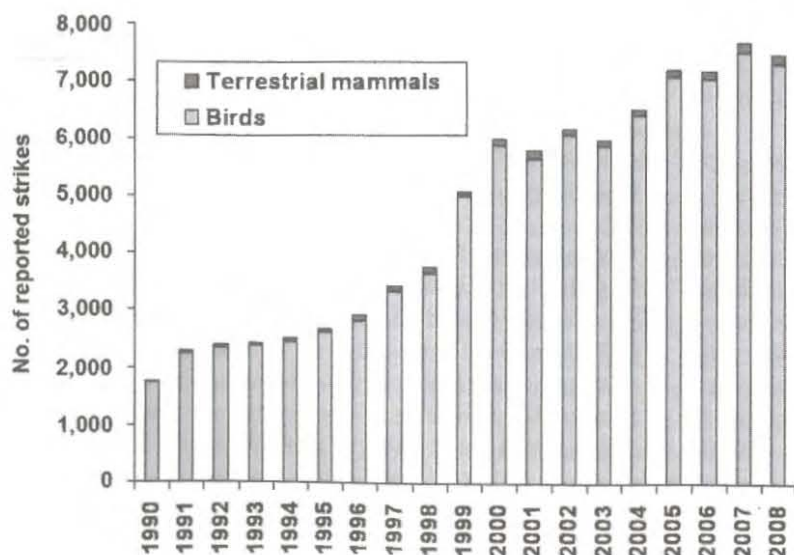


Fig. 34.2. Number of reported bird ($N = 87,416$) and terrestrial mammal ($N = 1,912$) strikes to civil aircraft, USA, 1990–2008. Additionally, 299 and 100 strikes involving bats and reptiles, respectively, were reported, for a total of 89,727 strikes by all species of wildlife. From Dolbeer et al. (2009).



Fig. 34.3. A template used for evaluating bird damage to sunflowers. Photo by U.S. Animal and Plant Health Inspection Service, Wisconsin.

Losses of agricultural crops to birds can be estimated indirectly through avian bioenergetics. By estimating the number of birds of the depredating species feeding in an area, the percentage of the agricultural crop in the birds' diet, the caloric value of the crop, and the daily caloric requirements of the birds, one can project the total biomass of crop removed by birds on a daily or seasonal basis (Weatherhead et al. 1982, White et al. 1985, Peer et al. 2003).

Species Damage Identification

Most bird damage occurs during daylight hours, and the best way to identify the species causing damage is by observation. However, the presence of a bird species in a location receiving damage does not automatically prove the species guilty. As one example, large, conspicuous flocks of common grackles (*Q. quiscula*) in sprouting winter wheat (*Triticum aestivum*) fields were found, after careful observation and examination of stomach contents, to be eating corn residue from the previous crop. Smaller numbers of starlings were removing the germinating wheat seeds (Dolbeer et al. 1979). As another example, detailed research showed that great blue herons (*Ardea herodias*) at catfish farms primarily fed on diseased, dying fish (Glahn et al. 2002). Below, the characteristics of damage for various groups of birds are described.

Gulls

Several gull species have adapted to existing in proximity to people, taking advantage of landfills and open trash containers for food. For example, a survey in 1994 revealed $\geq 15,000$ nesting ring-billed (*Larus delawarensis*) and herring gulls (*L. argentatus*) in >30 colonies on roofs in U.S. cities on the Great Lakes (Dwyer et al. 1996). Besides causing structural damage to roofs, gulls increasingly cause problems in urban areas by begging for food, defacing property, and contaminating municipal water supplies (Belant 1997). Gulls are a serious threat to flight safety at airports (Fig. 34.4), repre-



Fig. 34.4. A Cessna 500 Citation crashed in a woodlot shortly after take-off from Wiley Post Airport, Oklahoma City, Oklahoma on 4 March 2008. Analysis of organic remains recovered from the aircraft by a U.S. Department of Agriculture biologist under the direction of the National Transportation Safety Board indicated the aircraft had struck at least one American white pelican (*Pelecanus erythrorhynchos*) during the initial climb (Dove et al. 2009). All 5 people on board were killed. Photo by U.S. Department of Agriculture.

senting 25% of the bird strikes with civil aircraft causing damage, 1990–2008 (Dolbeer et al. 2009). In rural areas, gulls sometimes feed on fruit crops and farm-reared fish and ducklings, and compete with threatened bird species for nest sites. **Control techniques** include habitat manipulation, screening and wire grids, mechanical and chemical frightening agents, toxicants, shooting, and nest destruction.

Blackbirds and European Starlings

The term "blackbird" loosely refers to a group of about 10 species of North American birds, the most common of which are the red-winged blackbird, common grackle, and brown-headed cowbird (*M. ater*). The European starling, a species introduced to North America in the late 1800s, superficially resembles native blackbirds and often associates with them. Together, blackbirds and European starlings constitute the most abundant group of birds in North America, comprising a combined population of >1 billion (Dolbeer 1990).

Blackbird damage to ripening corn, sunflowers, and rice can be serious (Dolbeer 1999, Blackwell et al. 2003). Much of this damage is done in late summer during the milk or dough stage of seed development. The seed contents of corn are removed, leaving the pericarp or outer coat on the cob. Blackbird damage to sprouting rice in the spring can be serious in localized areas.

Starling depredations on grain and fruit crops and impact on livestock health cost American agriculture an estimated \$800 million annually (Pimentel et al. 2000). Starlings foraging at feedlots in winter can cause substantial losses

(Glahn et al. 1983, Linz et al. 2007a) and disease concerns (LeJeune et al. 2008). Although contamination of livestock feed by starling feces is often a concern of farmers, a study indicated that this contamination did not interfere with food consumption or weight gain of cattle and pigs (Glahn and Stone 1984). Starlings can seriously damage fruit crops such as cherries and grapes (Dolbeer et al. 1994a).

Perhaps the greatest problem caused by blackbirds and starlings is their propensity to gather in large, nocturnal roosting **congregations**, especially in winter (Dolbeer et al. 1997). The noise, fecal accumulation, and general nuisance caused by millions of birds roosting together near human habitations can be significant (White et al. 1985). Roosting birds near airports can create a safety hazard for aircraft; and roost sites, if used for several years, can become focal points for the fungus that causes **histoplasmosis**, a respiratory disease in humans (Tosh et al. 1970). **Control techniques** include habitat manipulation, cultural practices (e.g., resistant crop varieties), proofing and screening, lasers, mechanical and chemical frightening agents, repellents, toxicants, trapping, and shooting.

Pigeons and House Sparrows

Pigeons and house sparrows are urban and farmyard birds whose droppings deface and deteriorate buildings. Around storage facilities, they consume and contaminate grain. Pigeons and sparrows may carry and spread various diseases to people, primarily through their droppings (Weber 1979). As occurs with congregations of blackbirds and starlings, droppings that are allowed to accumulate over several years may harbor spores of the fungus that causes **histoplasmosis**. Sparrows build bulky grass nests in buildings, drain spouts, and other sites, where they can cause fire hazards or other problems. Flocks of pigeons at airports pose a hazard to departing and arriving aircraft (Dolbeer and Wright 2009). **Control techniques** include screening and proofing, overhead wires, trapping, toxic and stupefying (alpha-chloralose) baits, shooting, and chemical reproductive inhibitors (pigeons).

Crows, Ravens, and Magpies

Crows, ravens (*C. corax*), and **magpies** are well-known predators of eggs and nestlings in other birds' nests. In certain situations, these species kill newborn lambs or other livestock by pecking their eyes (Larsen and Dietrich 1970). Magpies sometimes peck scabs on freshly branded cattle.

Crows occasionally damage agricultural crops such as sprouting and ripening corn, apples (*Malus* spp.), and pecans (*Carya illinoensis*). Most of this loss is localized and minor. Crow damage to apples can be distinguished from damage by smaller birds by the deep (up to 5 cm), triangular peck holes (Tobin et al. 1989). Tree-roosting congregations of crows in urban areas cause nuisance problems because of noise and feces (Gorenzel et al. 2002). **Control techniques** include

mechanical frightening devices, distress calls, lasers, shooting, trapping, chemical frightening agents, and toxicants.

Hérons, Egrets, and Cormorants

These species sometimes concentrate at fish-rearing facilities and cause substantial losses (Dorr and Taylor 2003). Salmon (*Salmo* spp.) smolts released in rivers in the north-eastern United States have suffered heavy depredation by **double-crested cormorants** (*Phalacrocorax auritus*). This species also has caused serious losses at commercial fishponds in the southern United States (Glahn and Brugger 1995). Nighttime observations are sometimes necessary to determine the depredating species, because some of these species will feed at night. **Control techniques** include habitat modification, screening, overhead wires, frightening devices, and shooting.

Raptors

The **raptors** most often implicated in predation problems with livestock (primarily poultry and game-farm fowl) are red-tailed hawks (*Buteo jamaicensis*), great-horned owls (*Bubo virginianus*), and goshawks (*Accipiter gentilis*; Hygnstrom and Craven 1994). Unlike mammalian predators, raptors usually kill only 1 bird/day. Raptor kills usually have bloody puncture wounds in the back and breast. **Owls** often remove the head. Raptors generally pluck birds, leaving piles of feathers. Plucked feathers that have small amounts of tissue clinging to their bases were pulled from a cold bird that probably died from other causes, and was simply scavenged by the raptor. If the base of a plucked feather is smooth and clean, the bird was plucked soon after dying. Raptors have large territories and are not numerous in any one area; therefore, the removal of 1 or 2 individuals will generally solve a problem.

Golden eagles occasionally kill livestock, primarily lambs (sheep) and kids (goats) on range. This predation can be locally severe in sheep-producing areas from New Mexico through Montana (Phillips and Blom 1988). Close examination is needed to identify an eagle kill. Eagles have 3 front toes opposing the hind toe, or hallux, on each foot. The front talons normally leave punctures about 2.5–5.0 cm apart in a straight line or small "V," and the wound from the hallux will be 10–15 cm from the middle toe. In contrast, mammalian predators usually leave 4 punctures or bruises from the canine teeth. Talon punctures are usually deeper than tooth punctures, and there is seldom any crushing of tissue between the talon punctures. If a puncture cannot be seen from the outside, one can skin the carcass to determine the pattern of talon or tooth marks. Often a young lamb is killed with a single puncture from the hallux in the top of the skull and punctures from the 3 opposing talons in the base of the skull or top of the neck (O'Gara 1978b, 1994).

Raptors, especially red-tailed hawks and kestrels (*Falco sparverius*), are frequently attracted to grassland areas at airports to hunt for rodents and large insects (Fig. 34.5; McIlveen et al. 1993, Garland et al. 2009). These birds can cause serious damage to aircraft when ingested into engines (Dolbeer and Wright 2009). **Control techniques** include proofing and screening, habitat modifications, modified herding techniques, frightening devices, trapping and translocation, and shooting.

Vultures

Population increases of turkey (*Cathartes aura*) and black (*Coragyps atratus*) **vultures** in North America since the 1970s have resulted in various conflicts with humans. Both species can cause **nuisance** problems when roosting on structures or in trees in urban areas (Avery et al. 2006). Because of their size (1.8–2.3 kg), vultures soaring near airports pose a threat to aircraft (Dolbeer and Wright 2009). Black vultures will prey on newborn livestock (Milleson et al. 2006).

Woodpeckers

Woodpeckers (family Picidae) at times cause damage to buildings with wood siding, especially cedar (*Cedrus* spp.) and redwood (*Sequoia sempervirens*; Fig. 34.6 [Evans et al. 1983, Belant et al. 1997]). The birds peck holes to locate insects, store acorns, or establish nest sites. They also damage utility poles (Tupper 2009). **Sapsuckers** (*Sphyrapicus* spp.) attack trees to feed on the sap, bark tissues, and insects attracted to the sap. This feeding can sometimes kill the tree or degrade the quality of wood for commercial purposes (Ostry and Nicholls 1976). Woodpeckers occasionally annoy homeowners by knocking on metal rain gutters and stovepipes to proclaim



Fig. 34.5. Red-tailed hawk utilizing grasslands between runways for capturing prey and, thus, creating potential for airstrikes. Photo by U.S. Animal and Plant Health Inspection Service, Minnesota.

their territories. **Control techniques** include exclusion, sticky repellents, live traps, snap traps, shooting, and frightening devices.

Ducks, Geese, and Sandhill Cranes

Damage by **ducks** (family Anatidae) and **cranes** (*Grus canadensis*) to swathed or maturing small-grain crops during the autumn harvest is a serious, localized problem in the northern Great Plains region (Knittle and Porter 1988). Damage occurs from direct consumption of grain and from trampling, which dislodges kernels from heads.

Canada (*Branta canadensis*) and snow geese (*Chen caerulescens*) grazing on winter wheat and rye (*Secale cereale*) crops

Fig. 34.6. Two acorn woodpeckers (*Melanerpes formicivorus*), shown feeding from acorn granaries. Buildings, fence posts, and utility poles have all been shown to provide ideal substrate for acorn woodpecker granaries. In places where human structures have encroached on woodpecker habitat, woodpeckers have found that human structures can provide excellent storage facilities for acorns. Photo by S. Tupper.



can reduce subsequent grain and vegetative yields (Kahl and Samson 1984, Conover 1988). Canada geese also can be a serious problem to sprouting soybeans (*Glycine max*) in spring and in fields of standing corn in autumn. Canada geese have adapted to suburban environments in the past 30 years, creating **nuisance** problems around parks and golf courses through grazing and defecation (Smith et al. 1999). Canada geese are the most serious bird **threat to aircraft** in North America (Dolbeer and Wright 2009, Dolbeer et al. 2009). **Control techniques** include mechanical frightening devices, lure crops, hunting, trapping and transplanting, overhead wires, capture with drug (alpha-chloralose), nest destruction, and chemical reproductive inhibitors (Canada geese).

Management Techniques

Modifications of Habitat and Cultural Practices

Habitat and cultural modifications can be implemented in many situations to make roosting, loafing, or feeding sites less attractive to birds. Although the initial investment of time and money may be high, these modifications often provide long-lasting relief. **Thinning** or pruning vegetation can cause roosting birds such as blackbirds and starlings to move, often increasing the commercial or aesthetic value of the trees or marsh at the same time (Micacchion and Townsend 1983, Leitch et al. 1997). Gull activity at airports can be reduced by **eliminating** standing water and prohibiting **landfills** in close proximity. The U.S. Federal Aviation Administration's policy is that solid-waste disposal sites should not be located within 3 km of any runway used by turbine-powered aircraft (Cleary and Dolbeer 2005).

The use of **lure or conservation crops**, where waterfowl or blackbirds are encouraged to feed, is sometimes cost-effective in reducing damage to nearby commercial fields of grain and sunflowers where **bird-frightening programs** are in place (Cummings et al. 1987, Linz et al. 2007b). **Bird-resistant cultivars** of corn, sunflower, and sorghum (*Sorghum* spp.) have shown effectiveness in reducing damage. For example, varieties of sweet and field corn with ears having long, thick husks difficult for blackbirds to penetrate sustain less damage than do varieties with ears having short, thin husks (Dolbeer et al. 1988a, 1995). Certain varieties of cherries are more vulnerable to bird damage than other varieties (Tobin et al. 1991). Use of endophytic fescue (*Festuca* spp.) turf grass may reduce grazing by geese (Washburn et al. 2007). Planting crops so that they do not mature unusually early or late also can reduce damage by blackbirds (Bridge-land and Caslick 1983). **Control of insects** in cornfields can make those fields less attractive to blackbirds and reduce subsequent damage to the corn crop (Dolbeer 1990).

Proofing and Screening

Plastic netting is cost-effective in excluding birds from individual fruit trees or high-value crops such as blueberries or grapes (Fuller-Perrine and Tobin 1993). **Netting** or wire screen-

ing can be used to exclude birds from rafter areas of airport hangars, undersides of bridges, fish hatcheries, and vent openings of buildings. **Ledges** on buildings designed or retrofitted at a 45° angle will prevent bird perching or nesting. Electrically **charged wires** or arrays of wire or **plastic spikes** installed on ledges and other sites can prevent birds from perching.

Parallel strands of monofilament lines or wires strung at 2.5–12-m intervals over ponds, landfills, and other structures can reduce gull activity (Blokpoel and Tessier 1984, Belant and Ickes 1996). **Monofilament lines** at 30–60-cm intervals repelled house sparrows from feeding sites (Agüero et al. 1991). Gulls and house sparrows are reluctant to fly through these strands even though the spacing is larger than their wingspans. **Overhead lines** also have excluded birds from fish hatcheries. Recommended spacing between wires is 60 cm for mergansers (*Mergus* spp.) and 30 cm for great blue herons (Salmon and Conte 1981). Heavy **plastic (polyvinyl chloride [PVC]) strips** hung from open doorways will help exclude starlings and other birds from buildings (Johnson and Glahn 1994).

Frightening Devices

Many **sonic and visual devices** are marketed, or home-made, to frighten birds. Birds usually **habituate** to such devices, no matter how effective they may be initially. Thus, 2 important rules are (1) never rely solely on one type of device for frightening, and (2) vary the use of devices by altering the timing and location of their use. The use of selected lethal control with **shotguns** can enhance the efficacy of frightening devices (Baxter and Allan 2008). Frightening devices are only as effective as the person deploying them.

Probably the most widely used frightening device is the **propane cannon**, which produces a loud explosion at timed intervals (Fig. 34.7; Washburn et al. 2006). Several models are marketed, including ones with automatic timers, remote activation, and rotating barrels. To be effective in frightening birds from crops, at least one cannon should be used for each 2 ha and the cannons should be moved every few days. An occasional shotgun patrol to reinforce the exploders is important (Dolbeer 1980), using either live ammunition or shell crackers. **Shell crackers**, fired from a 12-gauge shotgun, shoot a projectile that explodes 50–75 m away. Other pyrotechnic devices for frightening birds include **rockets and whistle bombs** (Cleary and Dolbeer 2005).

Recorded **alarm and distress calls** of birds broadcast over a speaker system sometimes work well to frighten birds (Bomford and O'Brien 1990). Some airports have speakers mounted on vehicles, from which personnel can broadcast these amplified calls for bird species frequently encountered during runway patrols. Shooting at birds with a shotgun is often used to reinforce the distress calls. These calls are commercially available for many bird species (Schmidt and Johnson 1983).

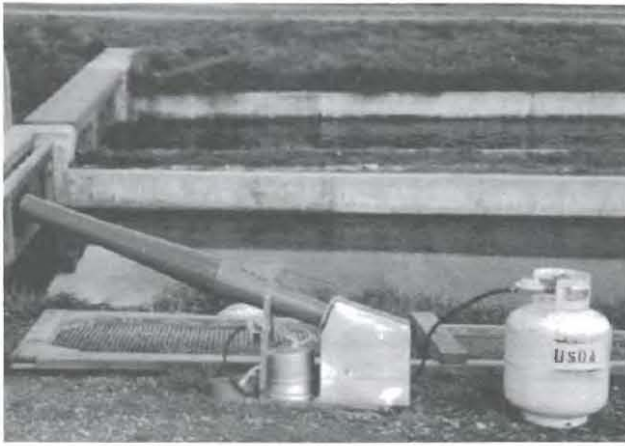


Fig. 34.7. Propane cannons used to alleviate damage caused by a variety of wildlife species. Photo by U.S. Animal and Plant Health Inspection Service, Wisconsin.

Ultrasonic devices emitting sounds with frequencies above the level of human hearing (20,000 Hz) are marketed for bird control in and around buildings. However, objective field tests have not demonstrated effectiveness of ultrasonic devices in repelling birds (Woronecki 1988). Most birds detect sounds in about the same range of frequencies as do humans.

Flags, helium-filled balloons with and without eyespots, and **hawk-kites** suspended from balloons or bamboo poles have been used with some success to repel birds from various sites (e.g., Conover 1984, Seamans 2002). **Mylar flags**, 15 cm \times 1.5 m in size, are used to keep geese from agricultural crops and gulls from loafing sites (Heinrich and Craven 1990, Belant and Ickes 1997); 10 flags/4 ha are recommended. Reflecting tape made of Mylar, strung in parallel lines at 3–7-m intervals, reduced blackbird numbers in agricultural fields (Dolbeer et al. 1986). Dead vulture (*Cathartes aura*, *Coragyps atratus*) and crow effigies suspended from structures or trees have caused abandonment of vulture and crow roosts (Seamans 2004, Avery et al. 2008b). **Inflatable human effigies** have been used to disperse cormorants from aquaculture facilities (Stickley et al. 1995). **Lasers** have been effective in dispersing Canada geese, cormorants, crows, and other species from nighttime roosting sites (Blackwell et al. 2002, Gorenzel et al. 2002). **Trained dogs and birds of prey** (falconry) are sometimes used at airports, landfills, and other sites to disperse various bird species (Cleary and Dolbeer 2005).

Blackbird roosts containing up to several million birds can be moved by use of a combination of devices, particularly recorded distress calls, shell crackers, rockets, and propane cannons (Mott 1980). **Strobe lights** placed in the roost also are helpful. The operation should begin before sunset, when the first birds arrive, and end at dark. People with shotguns and shell crackers should be stationed on the perime-

ter of the roost to intercept flight lines as they enter the roost. Three to five nights of harassment may be required to achieve complete dispersal. If not done as a part of the dispersal program, the habitat of the roost should be altered (e.g., tree thinning) after dispersal is achieved to discourage the roost from reforming. **Compressed air** has been used to disperse starling roosts in urban areas where loud, explosive noises were unacceptable (White et al. 2005).

Repellents

Birds have a poor sense of smell and taste in general, and repellents based on these senses are usually not effective (Rogers 1974, Belant et al. 1998b). For example, naphthalene crystals, although registered as an **odor repellent** for starlings, pigeons, and house sparrows in indoor roosts, have not been effective in field trials (Dolbeer et al. 1988b). **Taste repellents** used as seed treatments to prevent consumption of germinating seeds also are of questionable value (Heisterberg 1983).

In contrast, chemicals that produce illness or adverse physiological response upon ingestion (i.e., **conditioned aversion**) appear to work well as bird repellents (Rogers 1974). Methiocarb, a carbamate insecticide, is a condition-aversive repellent that has been used as a seed treatment for corn (applied as a powder to the seed at planting) and as a spray treatment for ripening cherries and blueberries (Dolbeer et al. 1994a). Another condition-aversive repellent, anthraquinone, has shown effectiveness in repelling geese from feeding on turf (Dolbeer et al. 1998, Blackwell et al. 1999). Formulations **containing methyl anthranilate**, a chemical that irritates the trigeminal nerve in birds, has had some success as a repellent (Belant et al. 1995).

Traps

European starlings and certain blackbird species often can be captured in **decoy traps**. A decoy trap is a large (e.g., 6 \times 6 \times 1.8-m) poultry-wire or net enclosure containing 5–20 decoy birds, food, water, and perches. Birds enter the trap by folding their wings and dropping through an opening (0.6 \times 1.2 m) in the cage top covered with 5-cm \times 10-cm welded wire to reach the food (cracked corn, millet) below. Decoy traps have been used to reduce local populations of starlings near cherry orchards (Bogatich 1967), to remove cowbirds from the nesting area of the endangered Kirtland's warbler (*Dendroica kirtlandii*; Kelly and DeCapita 1982), and to capture blackbirds for banding and research purposes. Pigeons and house sparrows can be captured in various **walk-in or funnel traps** (Corrigan 1989). **Mist nets** can be used to remove house sparrows around barns and small farm plots (Plesser et al. 1983).

Various trapping techniques are used to capture raptors, including **bal-chatri traps**, harnessed pigeons, **Swedish goshawk traps**, **bow nets**, and **padded leg-hold traps** (Bloom 1987). Raptors often become wary to one trapping technique,

requiring the use of 2 or 3 different techniques before successfully capturing some birds. Golden eagles preying on livestock can be captured for translocation with a **net gun** fired from a helicopter (O'Gara and Getz 1986).

Shooting

Shooting can be effective in reducing local populations of depredating or hazardous birds (Dolbeer et al. 1993). For example, a skilled shooter with an air rifle (pellet gun) can efficiently remove pigeons roosting and nesting inside buildings. For large populations of flocking birds, shooting may have little impact on the overall population (Dolbeer 1998), but can enhance efforts to repel birds from areas needing protection (Dolbeer et al. 2003, Baxter and Allan 2008, Taylor and Strickland 2008). This concept has been promoted in Wisconsin through a hunter referral program in which farmers allow goose hunters to shoot in agricultural fields experiencing chronic damage (Heinrich and Craven 1987).

Reproductive Control

Development of effective methods for reducing populations of overabundant nuisance bird species using contraception has been difficult to implement because of the lack of a safe, approved **avian contraceptive**. Since 2005, however, nizarbazin has received regulatory approval in the United States for use as a bait-delivered means to decrease hatchability of resident Canada goose and feral pigeon eggs (Bynum et al. 2007, Avery et al. 2008a). As with toxicants (discussed below), the challenge is delivering the proper dosage of bait to the target population. **Egg oiling** is another technique to inhibit hatching in Canada geese and gull populations (Cummins et al. 1997, Blackwell et al. 2000).

Toxicants and Capture Agents

The use of **toxic baits** to kill pest birds without harming nontarget organisms requires patience and a thorough understanding of the habits and food preferences of the target species. Prebaiting for several days with untreated bait is critical to enhance bait acceptance, to assess the amount of toxic bait to be used, and to assess possible nontarget hazards. Other nearby sources of preferred food should be restricted as much as possible during the prebait period. Strict control must be maintained over the toxic bait. Dead birds should be collected at least daily and buried in an approved location.

DRC-1339 is an EPA-registered toxicant incorporated into poultry pellets and marketed as Starlicide Complete® (Earth City Resources, Bridgeton, MO) for killing starlings at feedlots and poultry yards. DRC-1339, incorporated into bread baits, also is registered for killing certain gull species that compete with threatened bird species for nest sites (Seamans and Belant 1999). DRC-1339 affects the renal and circulatory systems, killing the bird 24–72 hours after ingestion.

Avitrol® is an EPA-registered frightening agent. The active ingredient, 4-aminopyridine, when ingested in small doses, causes the affected bird to emit distress calls while flying in erratic circles. The affected bird usually dies within 0.5 hours, but its initial behavior can act to frighten other birds away. Avitrol is registered for use on pigeons, gulls, house sparrows, starlings, and blackbirds around structures and nesting and roosting sites; for European starlings in feedlots; for gulls at airports; and for blackbirds in corn and sunflower fields. Avitrol-treated bait is usually diluted 1:10 or 1:99 with untreated bait so that only a portion of the birds feeding is affected (Woronecki et al. 1979).

Alpha-chloralose is a drug that can be mixed with corn or bread baits to immobilize and capture nuisance waterfowl, coots (*Fulica* spp.), and pigeons. Birds typically become immobilized 30 minutes after ingesting bait and fully recover 4–24 hours later (Woronecki et al. 1992). Alpha-chloralose is restricted by the U.S. Food and Drug Administration for use by biologists of Wildlife Services, U.S. Department of Agriculture (Belant et al. 1999).

UNGULATES

Damage Assessment

In North America, ungulates associated with damage to resources are typically members of the **deer** (Cervidae) and **swine** (Suidae) **families**. They include native species such as white-tailed deer (*Odocoileus virginianus*), mule deer (*O. hemionus*), and Rocky Mountain elk (*Cervus canadensis nelsoni*), as well as introduced species like fallow deer (*Dama dama*), red deer (*C. e. barbarus*), feral swine (*Sus scrofa*), and feral goats (*Capra hircus*). Populations of some species of ungulates, primarily white-tailed deer (Côté et al. 2004), elk (Bradford and Hobbs 2008), and feral swine (Gipson et al. 1998, Ditchkoff and West 2007), have been increasing steadily in recent decades. **Overabundant populations** of ungulates commonly cause a variety of types of damage at local, regional, and landscape scales. Ungulates damage plants in natural, agricultural, forestry, and urban settings, resulting in losses in billions of dollars each year (Fig. 34.8; Conover 2002). Ungulates also can transmit diseases to livestock and humans and threaten human safety when involved in collisions with vehicles—including airplanes. Repair costs associated with **deer-vehicle collisions** exceed \$1.6 billion annually (Conover 2002).

Cervids feed on various agricultural crops, especially soybeans, corn (see Fig. 34.8B), and alfalfa (*Medicago* spp.). Yield reductions in soybean fields are most severe when feeding occurs during the first week of sprouting (deCalesta and Schwendeman 1978), and corn yield is affected most when feeding occurs during the silking-tasseling stage (Hygnstrom et al. 1991). When food-stressed, cervids also may feed on and contaminate stored crops, imposing risk for disease transmission to livestock (VerCauteren et al. 2003b).

Fig. 34.8. Urban and rural damage caused by ungulates includes (A) deer browse resulting in deformation of individual trees by browsing, (B) crop damage by deer, (C) rooting by feral swine, and (D) stripping of bark through antler rubbing by elk. (A) Photo by S. Hygnstrom; (B) photo by G. Clements; (C) photo by T. Campbell; (D) photo by G. Clements.



Furthermore, increasing ungulate densities around stored feed increases the potential for disease transmission within and among species.

Cervids damage fruit and ornamental trees, as well as trees planted for timber production, by browsing (see Fig. 34.8A) and antler-rubbing (see Fig. 34.8D; Maas-Hebner et al. 2005). **Browsing** buds of fruit trees during the first year following planting has the greatest effect on fruit production; thus, this is the most important time to exclude deer (i.e., Mower et al. 1997). Similar browsing on nursery plants and in Christmas-tree plantations can diminish market values (Scott and Townsend 1985). Browsing of hardwood saplings and young Douglas-fir (*Pseudotsuga menziesii*) trees in regenerating forests can result in long-term effects (i.e., Horsley et al. 2003), including reduced growth rates, misshapen trees, and even plantation failures. **Antler-rubbing**, to remove velvet and hone sparring skills for the mating season (rut), can damage or kill trees. On larger spatial scales, overabundant populations of cervids can have deleterious effects on entire biotic communities (deCalesta 1994, Waller and Alverson 1997, Wisdom et al. 2006).

Feral swine include escaped domestic swine that have reverted to living in the wild and exotic wild boar that were introduced, as well as hybrids of the two (Mungall 2000). Annual costs associated with feral swine damage alone were estimated at \$1.5 billion (Pimentel et al. 2005). Unlike other ungulates that are strictly herbivorous, feral swine are omnivorous. Feral swine consume mast and seedlings, thereby affecting forest regeneration. **Rooting** by feral swine accel-

erates erosion and facilitates the spread of exotic plant species that thrive in disturbed environments (Seward et al. 2004). Biological, physical, and chemical properties of soil also can be altered through rooting and defecation (Moody and Jones 2000). Besides being destructive to vegetation, feral swine can be predatory and pursue wildlife (Roythe 1995, Seward et al. 2004) and domestic animals (Choquenot et al. 1997). Feral swine are effectual reservoirs of an array of diseases (i.e., Williams and Barker 2001, Meng et al. 2009) that could be transmitted to domestic swineherds through interactions that have been documented to occur between wild and domestic populations (Wyckoff et al. 2005). Feral swine also wallow in and around water sources, thereby increasing potential for disease contamination (Atwill et al. 1997, Jay et al. 2007).

Species Damage Identification

Cervids

Identification of cervid damage is not difficult, because the culprits are often observed causing damage. In addition, their **tracks** are readily identifiable. Cervids lack upper incisors and, therefore, leave a rough, shredded break on the twigs and stems they browse. Vegetation fed upon by rodents and lagomorphs, however, shows a neat, sharp-cut edge. Evidence of browsing damage higher than rodents or lagomorphs can reach also is indicative of cervid damage (taking into account that these smaller animals can cause damage higher on vegetation when standing on snow). **Mule and white-tailed deer** damage typically occurs from ground level to

1.8 m and they seldom browse on branches >2.5 cm in diameter. **Moose** (*Alces alces*) and **elk** damage can reach 3 m in height and they will use their incisors to scrape the bark of aspen (*Populus tremuloides*) trees. In the autumn, male cervids rub the velvet from their antlers, often removing tree bark in the process. Scarring is generally confined to the trunk up to 1 m high for mule and white-tailed deer and up to 2 m for elk.

Feral Swine

Rooting by feral swine is readily visible, because they turn over soil in search of roots and tubers, and in the process cause damage to yards, pastureland, crops, and native habitats. Depending on the number of swine present, rooted areas can exceed an acre (0.40 ha) in size and damage can be several feet deep. **Mud-covered rubs** on nearby trees and power poles (see Fig. 34.8C) are common indicators of swine activity. Predation by feral swine can be difficult to ascertain because complete consumption often occurs. Identification must often be made by locating other signs of swine presence such as tracks, rubs, or rooting.

Management Techniques

The public generally approves of **nonlethal** management techniques, especially in urban settings, where traditional hunting may not be considered safe, yet damage levels are high. Although population reduction through lethal means is often necessary to reduce ungulate damage to tolerable levels, many nonlethal strategies may have a role in a comprehensive ungulate management program. However, limited effectiveness and high cost of nonlethal strategies frequently make them economically impractical, even when used in conjunction with lethal strategies. Frequently, the efficacy of nonlethal techniques is directly correlated to the level of motivation of the targeted individuals. For example, a simple frightening device employing sound and lights or a single strand of electric fence may be a sufficient deterrent to minimize deer use of a minimally desired resource; however, strongly motivated deer can breach a 2.1-m-high woven-wire mesh fence. The management technique chosen for a scenario under one level of motivation may have a different degree of success in dissimilar scenarios. Thus, the

level of motivation of the targeted individuals must be considered prior to implementation of any nonlethal technique.

Habitat and Food Modifications

Reduction of permanent cover in a localized area can effectively manage damage by reducing ungulate carrying capacity, though it also destroys habitat important to other wildlife. Selecting plants that are less palatable or are resistant to ungulate damage can minimize ungulate damage to plantings in urban areas. Craven and Hygnstrom (1994) present a list of common plants and their susceptibility to damage. Agricultural crops should be harvested as early as possible to minimize the time during which they are susceptible to damage. **Lure crops** can be used to draw ungulates away from more valuable crops (Schwab et al. 2001), but providing this additional forage could lead to higher densities, resulting in increased damage. Similarly, feeding and baiting ungulates ultimately leads to increased local damage. **Supplemental feeding** can result in higher reproductive and survival rates, and lead to congregated and tame populations (Doenier et al. 1997). It also makes the ungulate population more susceptible to diseases (Davidson and Nettles 1997, Garner 2001), some of which can be spread to other species of wildlife and livestock.

Exclusion

Frequently, the only long-term, nonlethal method to effectively minimize ungulate damage is **fencing**. Many fence designs are available (Fig. 34.9), although an effective yet low-cost design has yet to be perfected. Fencing provides protection in 1 of 3 ways: (1) as a physical barrier, (2) as a psychological barrier, or (3) as a combination of 1 and 2. The standard deer fence, a 2.4-m-high woven-wire fence, is a physical barrier and greatly reduces the possibility of an animal passing through, over, or under it. Conversely, a single- or double-strand electric poly-tape fence acts as a psychological barrier through aversive conditioning. **Conditioning** occurs when an animal attempts to breach the fence and receives a powerful electric shock. This training can be expedited with the use of bait such as peanut butter applied directly to the fence (i.e., Porter 1983). Some fences, such as a 2.4-m-high, 11-strand high-tensile electric fence, increase the efficacy of the barrier by incorporating both concepts.

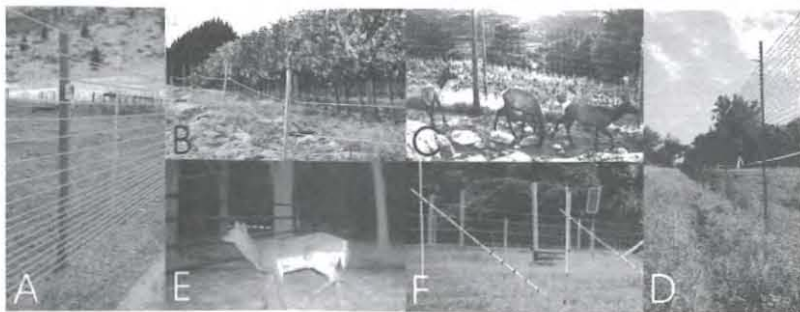


Fig. 34.9. Examples of fence types for ungulate control: (A) multistrand, electrified high-tensile steel, (B) 2-strand, electrified poly-rope for hogs, (C) high, woven-wire mesh, (D) high polypropylene mesh, (E) baited, electrified poly-tape, and (F) slanted, electrified poly-rope. (A) Photo by M. Lavelle; (B) photo by D. Hewitt; (C) photo by J. White; (D) photo by J. White; (E) photo by U.S. Animal and Plant Health Inspection Service, Wisconsin; (F) photo by K. VerCauteren.

Broad classes of **fence designs** include woven-wire mesh, high-tensile, poly-mesh, and electrified poly-tape or poly-rope (VerCauteren et al. 2006a; Table 34.1). Variables to be considered when deciding on the most appropriate fence design to construct include (1) level of protection desired, (2) seasonality of the resource being protected, (3) physical ability of the target species, (4) motivation to breach, (5) behavioral characteristics, (6) costs associated with constructing and maintaining the fence, (7) longevity of the fence, and (8) possible negative effects of erecting a fence (VerCauteren et al. 2006c). While fencing may have the potential to eliminate damage, its expense may make it cost-prohibitive, especially in situations where the value of the resource being protected is low and the area to be protected is large (VerCauteren et al. 2006b), such as with many agricultural crops. In addition, size, shape, and perimeter of the area influence the amount of fencing required and, thus, the cost (Conover 2002).

Alternatives to fencing that provide protection for individual trees or tree parts include: **tree cylinders**, **tree wraps**, and **bud caps** (deCalesta and Witmer 1994). These devices reduce damage by preventing access to the roots, stems, vegetation, and growing points until plants are no longer highly vulnerable to serious damage. One benefit of these damage reduction tools is that they do not completely exclude animals from large portions of their habitat; thus, they may be preferred in some settings. One must consider number of plants (usually tree seedlings) and size of area being protected, because at \$5/seedling protected (Kimball et al. 2008), individual plant protection expenses may approach the expense of fencing. Chicken-wire **cylinders**, photodegradable polypropylene cylinders, and a variety of flexible mesh **sleeves** can effectively protect seedlings (i.e.,

Taylor et al. 2006). Protective cylinders provide protection only until the terminal bud protrudes from the top of the cylinder, becoming accessible to ungulates. It may be advantageous to apply bud caps at this time.

A variety of fence designs have been used to minimize damage caused by feral swine. Sturdy wire mesh is reliable and effective as long as it is tight to the ground. Fence also must be rigid enough to deter swine from climbing over it. An evaluation of electrified poly-rope for excluding feral swine proved promising (see Fig. 34.9B; Reidy et al. 2008). Traditional 0.86-m rigid-wire **hog panels** are quite effective in controlling the movements of feral hogs. Similar to cervids, feral swine (when not especially motivated) can be deterred simply by adding a single strand of **electrified wire** offset from an existing fence (Hone and Atkinson 1983).

The weakest link in a potentially effective fence is most often the gate, which must be closed to be effective. Considerable research into alternatives to traditional gates for deer has been conducted with varying results (Fig. 34.10). **Automatically closing gates** (see Fig. 34.9A and D; VerCauteren et al. 2009), **electrified mats** (see Fig. 34.9C; Seamans and Helon 2008), and **active** (see Fig. 34.9B; VerCauteren et al. 2009) and **passive cattle-guard type devices** (i.e., Peterson et al. 2003b) have been evaluated with mixed success.

Frightening and Hazing

Propane cannons, flashing **lights**, shell crackers, and other **sonic devices** used near a resource can provide temporary relief from ungulate damage (Gilsdorf et al. 2002). Ungulates adjust or **habituate** to frightening devices rather quickly, and these devices are generally not effective for an entire growing season. Recent research has evaluated the efficacy of **animal-activated** frightening devices, with mixed results

Table 34.1. Fence types including cost, height, efficacy level, longevity, and level of required maintenance

Fence type	Cost	Height (m)	Efficacy	Longevity (yr)	Maintenance
Woven-wire mesh	>6.00	3.0	High	30–40	Low
Chain link	>6.00	2.4	Moderate–high	30–40	Low
Polypropylene mesh	4.00–6.00	2.3	Moderate–high	10–20	Medium
Electrified poly-rope (9-strand)	4.00–6.00	1.8	Moderate	20–30	Medium
Welded-wire mesh	4.00–6.00	3.0	High	20–30	Low
Plastic snow fence	4.00–6.00	2.1	Moderate–high	5–10	Medium
Modified woven-wire with 2-strand barbed-wire	4.00–6.00	2.4	Moderate–high	20–30	Medium
Modified woven-wire with 5-strand high-tensile	4.00–6.00	2.4	Moderate–high	20–30	Medium
Barbed-wire (18-strand)	2.00–4.00	2.4	Moderate	20–30	Medium
Nonelectrified 15-strand high tensile	0.50–2.00	2.4	Moderate	20–30	Medium
New Hampshire (electrified, offset 3-strand)	0.50–2.00	1.0	Low	20–30	High
Slanted 7-strand electrified high-tensile	0.50–2.00	1.5	Moderate	20–30	High
Penn State 5 (5-strand electrified high-tensile)	0.50–2.00	1.1	Moderate	20–30	High
Electrified 2-strand poly-tape	0.50–2.00	0.9	Low	5–10	High
Nonelectrified 8-strand high-tensile	0.50–2.00	1.8	Low	20–30	High
Peanut butter-baited electric	0.50	1.1	Low	10–20	High



Fig. 34.10. Several different alternatives to traditional gates are being used or evaluated, including (A) Texas-style bump-gate, (B) research prototype deerguard, (C) electrified mat, and (D) commercially available BumpGate™. (A) Photo by K. VerCauteren; (B) photo by N. Seward; (C) photo by U.S. Animal and Plant Health Inspection Service, Wisconsin; (D) photo by M. Lavelle.

(i.e., Belant et al. 1998a; Gilsdorf et al. 2004a, b; Beringer et al. 2003). **Infrared beams** or passive infrared sensors activate these new devices when triggered by ungulate-sized animals. Beringer et al. (2003) significantly reduced soybean damage with a deer-activated system that randomly played **sounds** chosen to frighten ungulates (i.e., aggressive dogs, barrages of gunshots, ungulate distress calls) and included an illuminated **human effigy**. Conversely, this same device minus the illuminated effigy was insufficient at protecting corn during the silking-tasseling stage from deer (Gilsdorf et al. 2004b).

Lasers, which are effective in dispersing some bird species, also are ineffective in dissuading deer (VerCauteren et al. 2003a, 2006a). A frightening device that provided physical stimuli deterred deer from using cattle feed (Fig. 34.11; Seward et al. 2007), suggesting that targeting the sense of touch can improve efficacy. Studies directed at using frightening devices to alleviate feral swine damage are lacking; thus, none can be recommended.

Dogs as a Deterrent

Dogs within the perimeter of an invisible fencing system that surrounds agricultural crops have been shown to reduce damage by deer (Beringer et al. 1994) and several producers are actively using dogs to protect orchards and annual crops (Curtis and Rieckenberg 2005, VerCauteren et al. 2005b). Dog selection, training, and care are important components to the success of this strategy. The use of dogs also has the potential to reduce transmission of disease in wild ungulates to livestock (VerCauteren et al. 2008).

Repellents

A variety of repellents has been evaluated to assess their ability to reduce ungulate damage (El Hani and Conover

1997, Wagner and Nolte 2001, MacGowan et al. 2004). There are 3 general categories of repellents: (1) odor, (2) contact, and (3) systemic. **Odor repellents** are ostensibly designed to repel animals from an area and either mimic predator odors (e.g., human or coyote [*Canis latrans*] hair) or are repugnant (e.g., mothballs, bone tar). Apfelbach et al. (2005) discussed the variability in efficacy of predator odors on mammalian prey species. Recent research suggests that so-called "**fear repellents**" (i.e., those associated with predator odors) reduce browsing by altering the palatability of the plant (Kimball and Nolte 2006). **Contact repellents** are applied directly to the targeted resource and are later ingested by the offending animal (i.e., Kimball et al. 2008). They function by



Fig. 34.11. Animal-activated frightening devices used to reduce disease-transmission risks between deer and livestock are being designed and evaluated. Photo by N. Seward.

changing the hedonic quality of the treated food item and/or causing illness (aversive conditioning). **Systemic repellents** are incorporated into plants, either naturally (e.g., tannins), by supplementation (e.g., selenium), or through genetic manipulation.

Although repellents should not be expected to eliminate damage (Craven and Hygnstrom 1994), they can be relatively inexpensive and effectively provide short-term protection. Repellents are most effective on vegetation during the dormant season, but results are frequently inconsistent. Even under optimal conditions, some damage usually occurs. As with other nonlethal techniques, factors such as ungulate population density, availability of alternate foods, target plant species, weather, repellent concentration, and duration of the problem can influence the effectiveness of repellents.

The history of pesticide regulations has compromised the effectiveness and marketing of repellents. In 1978, amendments to the **Federal Insecticide Fungicide and Rodenticide Act** gave the Environmental Protection Agency the option to waive data submission requirements for efficacy of pesticides. The EPA took advantage of this provision except for certain public health uses (Jacobs 2002). In 1982, the waiver was extended to all vertebrate pesticide products, but within 2 years, data submission requirements for public health uses were fully reinstated with the added proviso that the waiver applied only to the submission of data and that EPA could request efficacy data for any product at any time. Armed with this option, the agency began to require submission of efficacy data for reregistration of products claimed to repel vertebrate pests; the efficacy of many such products had been in question for several years. The **Office of Pesticide Programs** reversed this policy in 1995, except for products making claims to repel pests of public health significance (Jacobs 2002). The result of these legislative actions is that efficacy data are not required for most products making claims to repel vertebrate pests, because these products are not typically labeled for public health uses (Jacobs 2002). As a result, there are many repellents currently on the market and many are not effective.

Fertility Control

Considerable effort has been expended to develop fertility control agents (contraceptives) for, and methods of delivery to, ungulates. **Contraceptives** for wildlife have potential to be a complementary tool for population management in scenarios where current nonlethal management techniques are ineffective or unacceptable. There are several contraceptive strategies including chemosterilants, immunocontraceptives, intrauterine devices, and surgical procedures that can all effectively result in decreased reproduction. Initially, Knipling (1959) proposed the principle that undesirable wild animal populations may be controlled with the use of **sterility-causing agents**. Shortly thereafter, Greer et al. (1968) field tested several methods on elk. Over the following 40+

years, much research was directed at the same goal, with an array of species, and using a variety of strategies. Researchers at the National Wildlife Research Center have explored an array of chemical and immunologically based contraceptives for wildlife (Mauldin and Miller 2007). Early immunocontraceptives proved inefficient and expensive because they required a booster or second shot (i.e., Walter et al. 2002). Recent developments in single-shot fertility-control methods (Hernandez et al. 2006, Locke et al. 2007) have received a great deal of attention and EPA registrations are being pursued. Orally delivered contraceptives, as well as live-vector (bacterial or viral) delivery, are being explored further (i.e., Fagerstone et al. 2002, Conner et al. 2007). However, it is unlikely that fertility control will become a viable stand-alone ungulate management strategy (Dolbeer 1998, DeNicola et al. 2000) beyond maintaining relatively small closed populations (Ruthberg et al. 2004).

Removal

Regulated, managed **hunting** in rural settings is the most practical and effective method of managing overabundant deer populations and controlling damage (Fig. 34.12A). It also is the most ecologically, socially, and fiscally responsible method. Some states have special depredation permits that can be issued to landowners to remove cervids in areas where they are causing damage outside the normal hunting season, if sufficient control cannot be achieved during the hunting season. Well-managed hunting also can be effective for reducing burgeoning deer numbers in urban settings (i.e., McDonald et al. 2007). Several case studies have outlined strategies to ensure the success of deer hunts in areas that also are densely populated with humans (McAninch 1995, VerCauteren and Hygnstrom 2002, Warren 2002). **Archery** hunting, under specific restrictions (e.g., earn-a-buck tags), can be a useful tool in an integrated management program to keep urban deer populations in check (Kilpatrick et al. 2004). Professional **sharpshooters** also have been employed effectively to reduce deer numbers (Fig. 34.12B) in areas where public hunting was not considered safe (i.e., DeNicola et al. 2000, DeNicola and Williams 2008).

In damage management situations, **live capture** and relocation of ungulates is generally a poor option, though it is sometimes mandated by safety considerations or sensitive public-relations issues. Ungulates can be captured with various designs of cage traps (see Fig. 34.12C), corral traps, rocket nets, drop nets, or via remote chemical immobilization, and then **euthanized or relocated**. It is important to realize that there are problems with holding animals humanely in captivity until they can be transported somewhere for release, and finding suitable release sites also is difficult. In many instances, shooting is a more effective and practical option. In areas such as arboretums, where shooting is normally prohibited, the use of skilled sharpshooters under permit is probably preferable to live capture (Ishmael

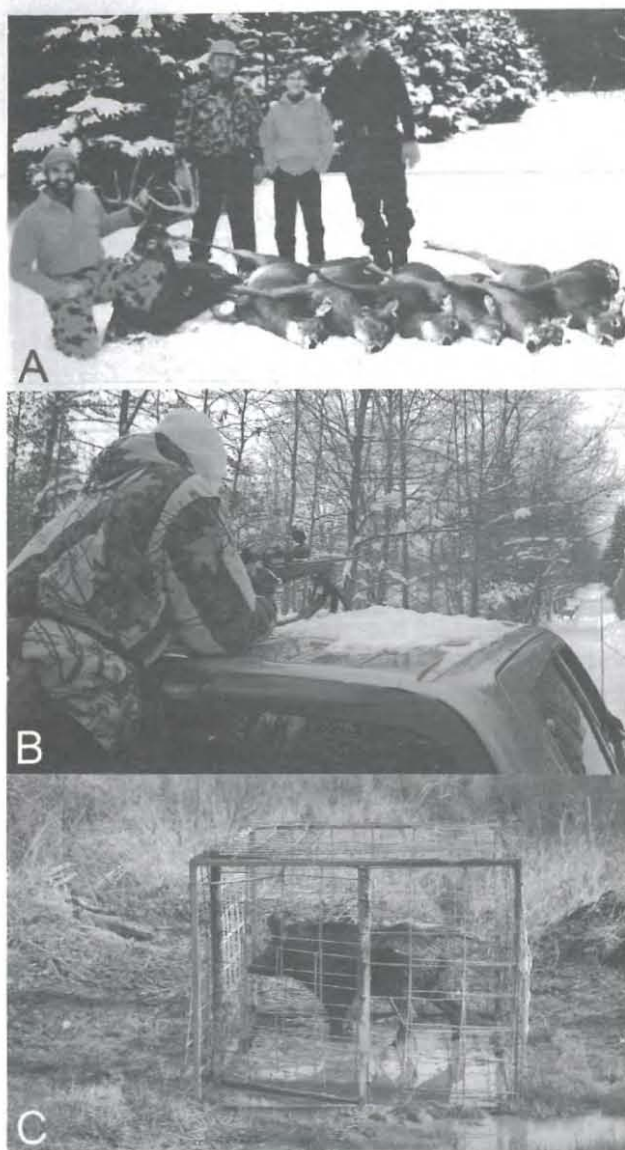


Fig. 34.12. Population control methods for ungulates include (A) well-managed hunting, (B) sharpshooting, and (C) trapping for euthanasia. (A) Photo by S. Hygnstrom; (B) photo by K. Malcom; (C) photo by M. Lavelle.

and Rongstad 1984, DeNicola and Williams 2008). Additional lethal tools such as **snares** and **toxicants** are occasionally recommended for limited use in specific situations and warrant further exploration.

RODENTS AND OTHER SMALL MAMMALS

Damage Assessment

Rodents and other small mammals are often not readily observed causing damage, and their damage is frequently difficult to measure and quantify. Likewise, accurate estimates of monetary losses of much of this damage are difficult to ascertain. Damage assessments indicate rodents and non-

predatory small mammals cause tremendous annual losses of food and fiber. Conover (2002) estimated the value of rodent damage to agriculture in the United States could be as high as **\$7 billion annually**. In the timber industry, **American beaver** (*Castor canadensis*) and **pocket gophers** cause the most damage. Miller (1987b) surveyed forest managers and natural resource agencies in 16 southeastern states and estimated annual wildlife-caused losses, primarily attributed to beaver, to be \$11.2 million on 28.4 million ha. Comparatively, in 1998, Louisiana expended \$2 million to control **nutria** (*Myocastor coypus*; Bounds and Carowan 2000). Other types of damage include losses of sugarcane (*Saccharum officinarum*) to **rats** (*Rattus* spp.), orchard damage by **voles** (*Microtus* spp.), and decreased forage quantity on rangelands caused by rodents and **lagomorphs** (rabbits and hares). In households, house mice (*Mus musculus*) are the primary species conflicting with humans.

Quantifying losses to evaluate efficacy of rodent-control techniques can be challenging. Most research compares plots where resources are protected to those with no protection, or agricultural production in areas with no rodents to areas with rodents. However, loss estimates must be converted to dollar losses to compare cost-benefit evaluation of control programs (VerCauteren et al. 2002a). Conversion to dollars is often difficult, given vast areas involved and variability in rodent populations. These considerations and the complexity of damage situations make it easy to realize the need for better monitoring techniques, damage assessment methods, and control effort evaluation.

Species Damage Identification

Most rodents and small mammals are nocturnal, secretive, and not easily observed. Often the investigator must rely on sign, such as **tracks**, **trails**, **tooth marks**, **feces**, or **burrows** to identify the species responsible for damage. Trapping may be necessary to make a positive identification of damage-causing rodents and, frequently, more than one species is involved. Characteristics of the damage may provide clues to the species involved. In orchards, for example, major stripping of roots is usually caused by pine voles (*Microtus pinetorum*), whereas damage at the root collar or on the trunk up to the extent of snow depth is most often caused by meadow voles (*M. pennsylvanicus*). Rats gnaw stalks of sugarcane until they are hollowed out between the internodes, but usually not completely severed. Rabbits (*Sylvilagus* spp.), in contrast, usually gnaw through stalks, leaving only the ring-shaped nodes. Damage to plants can generally be grouped as (1) root damage—pocket gophers and pine voles, (2) trunk debarking—meadow voles, squirrels (family Sciuridae), porcupines (*Erethizon dorsatum*), woodrats (*Neotoma* spp.), rabbits, and mountain beavers (*Aplodontia rufa*), (3) stem and branch cutting—beavers, rabbits, meadow voles, mountain beavers, pocket gophers, woodrats, squirrels, and porcupines, (4) needle clipping—mice, squirrels, mountain beavers, porcupines, and rabbits, and (5) debudding—red squirrels (*Tam-*

iasciurus hudsonicus and *T. douglasii*) and chipmunks (*Tamias striatus* and *Eutamias* spp.). These characteristics can aid in identification of the responsible species, but positive identification should be made either by species-specific sign (e.g., tracks, feces) or by capture of individuals.

Bats

Bats, the only mammals capable of true flight, eat vast quantities of insects. Only a few of the 190 species of bats in North America cause problems. Problems primarily occur when they form roosts or maternity colonies in **human dwellings** or structures. Those most commonly encountered in pest situations are: little brown bat (*Myotis lucifugus*), big brown bat (*Eptesicus fuscus*), Mexican free-tailed bat (*Tadarida brasiliensis*), pallid bat (*Antrozous pallidus*) in the Southwest, and the Yuma myotis (*M. yumanensis*) in the West (Greenhall 1982, Frantz 1986). Species identification may be difficult, but is important because several bat species are threatened or endangered and protected by state and federal laws.

Besides seeing bats, their presence also can be evidenced in buildings by noise (squeaking, scratching) and a distinctive pungent odor of accumulated feces and urine. Bat feces are readily differentiated from those of rodents by odor, insect content, and ease with which they are crushed. Many people are fearful of bats and panic in their presence. Bats can carry and transmit **rabies**, although 0.05% of bats are thought to be rabid (Fitzgerald et al. 1994). However, because infected bats may exhibit weakness or paralysis, they are often unable to fly or roost and, therefore, pose a greater risk of contact with humans and domestic animals. Where bat colonies are allowed to persist, fecal deposits accumulate, and the fungus that causes **histoplasmosis** can develop. **Damage management techniques** involve education to overcome phobias, habitat modifications (1-way valve devices on structures after young reach flight stage, and construction of artificial roosts), repellents (naphthalene), and traps.

Beaver, Muskrat, and Nutria

A decline in traditional trapping combined with increased restrictions on use of specific trap designs are resulting in proliferation of beaver populations in parts of the United

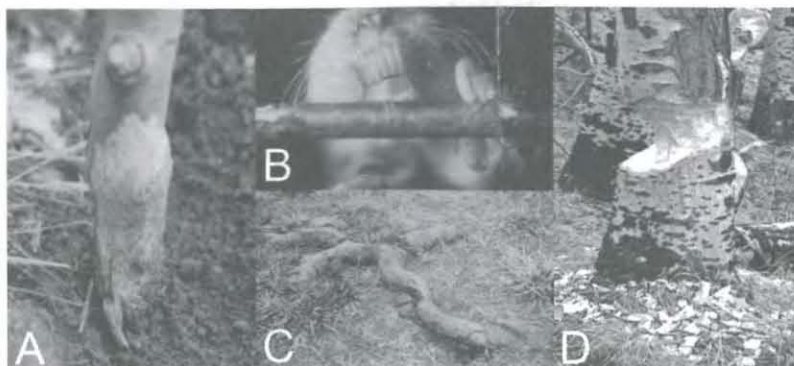
States. Burrowing aquatic rodents, as agents of disturbance, can alter habitats in positive and negative ways. **Beaver, muskrat** (*Ondatra zibethicus*), and **nutria** are aquatic rodents that can cause damage in and around natural and human-created wetlands. Due to their burrowing habits, they cause damage to manmade dams, levees, and irrigation canals. The presence of these species is evidenced by the damage they cause and by their tracks, droppings, and trails. Beaver and muskrat are native to North America and nutria was introduced from South America. The regulations regarding control of these species vary from state to state.

Beaver damage is easily identified by the distinctive, cone-shaped tree stumps that result from their gnawing (Fig. 34.13D). Other beaver sign includes dams, lodges, bank burrows, and green sticks with the bark freshly peeled off. Beaver eat a wide variety of plant species, but are usually locally selective, which can result in overexploitation of preferred species (Fitzgerald et al. 1994). Damage caused by beaver results from feeding behavior (tree cutting) and their efforts to control water levels (dam building; Miller and Yarrow 1994). Beaver girdle and fell large-diameter trees to access the branches, contributing to losses in timber value (Fitzgerald et al. 1994). They also cause flooding of roads, dwellings, and other human property.

The most serious damage caused by **muskrats** is wash-outs and cave-ins of pond dams, levees, and irrigation canals. They also can cause severe damage to grain, such as rice, and to garden crops growing near water. Their cone-shaped huts of aquatic material projecting 0.5–1.0 m above the water surface, feeding platforms of aquatic vegetation, and burrow entrances indicate muskrat presence. Their burrow entrances, 13–17 cm in diameter, are much smaller than those of nutria. Muskrat and nutria are smaller than beaver and do not build dams or plug culverts.

Nutria can cause significant damage to rice and sugarcane, especially in fields adjacent to Gulf Coast marshes (LeBlanc 1994). They may severely impede cypress (*Taxodium distichum*) regeneration (Conner and Toliver 1987) and damage wooden structures and floating marinas. Nutria also have been implicated as a threat to the persistence of coastal marshes (Ford and Grace 1998). The presence of nutria can

Fig. 34.13. Examples of rodent damage: (A) tree damage in orchards by voles, (B) damage to underground cables by pocket gophers, (C) soil cast left by pocket gophers, and (D) beaver damage to trees. (A) Photo by U.S. Animal and Plant Health Inspection Service, Wisconsin; (B) photo by U.S. Animal and Plant Health Inspection Service, Wisconsin; (C) photo by U.S. Animal and Plant Health Inspection Service, Wisconsin; (D) photo by N. Seward.



be verified by identification of scat, which has distinctive parallel lines running along its length (LeBlanc 1994).

Beaver, muskrat, and nutria can be infected with several pathogens and internal and external parasites that can be transmitted to humans (e.g., Davidson and Nettles 1997). Proper water-treatment measures should be taken before drinking water in regions where these species occur. Permissible **damage management techniques** vary by state and include habitat modification (explosives for dams, drain devices in dams or culverts), exclusion, traps (live traps accompanied by translocation, Conibears, footholds), snares, and shooting.

Deer and White-Footed Mice

Deer and white-footed mice (*Peromyscus maniculatus* and *P. leucopus*, respectively) are common and widely distributed throughout North America (Timm and Howard 1994). These mice are nocturnal, active year-round, and their populations may show large fluctuations. Their cheek pouches give them the capacity to carry 3–5 times more food than other species of mice and may increase their efficiency in exploiting small, particulate food items that are patchily distributed (Vander Wall and Longland 1999). *Peromyscus* can be significant seed predators (Sullivan 1978), and in some areas direct seeding for reforestation has failed because of their foraging activities. Their effects on reforestation have caused a shift to the use of hand-planted seedlings in many areas. *Peromyscus* also can cause significant losses to corn seedlings in conservation tillage systems, but this damage may be offset by their consumption of harmful insects and weed seeds (Clark and Young 1986, Johnson 1986). *Peromyscus* invade homes, where they eat stored food and damage upholstered furniture or other materials that are shredded for use in nest building. Trapping with snap or live traps is the best method to identify the species present. **Damage management techniques** for *Peromyscus* include habitat and food modifications, exclusion, traps (snap traps and live traps), repellents, and toxicants. Species of *Peromyscus* are the primary reservoirs of the **Sin Nombre hantavirus** (Corrigan 2001), which is the cause of an often-fatal pulmonary syndrome in humans.

Ground Squirrels

Ground squirrels, genus *Spermophilus*, are important pest species in north-central and western North America, causing serious economic losses to agricultural and range resources. Belding's (*S. beldingi*), California (*S. beecheyi*), rock (*S. variegatus*), and Richardson's (*S. richardsonii*) ground squirrels are all considered pests in at least part of their range (Marsh 1994a, Johnson-Nistler et al. 2005). They can inflict serious damage to pastures, forage crops, rangelands, vegetable gardens, and grain, fruit, or nut crops.

A careful search of an area showing damage will reveal opened seed hulls and caches. They often live in colonies or concentrate in localized areas (Marsh 1994b). As a group,

ground squirrels are widely recognized for their ability to achieve high population levels in suitable habitats (Giusti et al. 1996). Ground squirrel burrows can collapse irrigation levees, increase erosion, damage farm machinery, and cause injury to livestock and humans. Ground squirrels also predate nests of ground-nesting birds (Renfrew and Ribic 2003), including those of waterfowl (Sargeant and Arnold 1984, Marsh 1994a).

Ground squirrels are diurnal and easily observed (Marsh 1985a). They hibernate and estivate and show major dietary shifts during the year (Marsh 1985a, 1986). Effective control strategies must consider these factors. Ground squirrels are extremely adaptable, so indirect control through habitat modification, exclusion, or use of chemical and visual repellents has limited, if any, benefit in most situations (Whisson et al. 2000). Ground squirrels carry several zoonotic diseases, including **plague**. In plague-endemic areas, ground squirrel control should be combined with ectoparasite control (Marsh and Howard 1982). **Damage management techniques** include habitat modification (exclusion, burrow ripping, and flooding), toxicants, fumigants, traps (live traps, size no. 0–1.5 foothold traps, snap traps), and shooting.

Marmots

Marmots (*Marmota* spp.), also known as **woodchucks**, can cause damage to a variety of crops and forage production may be markedly reduced by marmot feeding and trampling (Marsh 1985a). Damage to crops such as alfalfa, soybeans, beans (*Phaseolus* spp.), squash (*Cucurbita* spp.), and peas (*Pisum* spp.) can be costly and extensive. They damage fruit trees and ornamental shrubs by gnawing or scratching woody vegetation (i.e., Swihart and Picone 1994). Damage often occurs on farms, in home gardens, orchards, nurseries, around buildings, and occasionally on dikes (Bollengier 1994). Their burrows, often positioned along field edges, can cause damage to farm machinery and injure livestock, and burrows can compromise the structural integrity of irrigation ditches, resulting in loss of water. In suburban areas, burrows under buildings or in landscaped areas cause problems (Marsh and Howard 1982). The presence of marmots is easily ascertained by direct observation of animals and burrows. During periods of forage growth, vegetation around burrows is noticeably shorter than in surrounding areas. Occupied burrows can be identified in spring by presence of dirt pellets ranging from marble to fist size. **Damage management techniques** include frightening devices, fumigants, traps (e.g., Conibear traps, foothold traps, live traps) and shooting.

Voies

Voies, also called meadow mice, field mice, and pine mice, cause extensive damage to forests, orchards, and ornamentals by gnawing bark and roots (Sullivan et al. 1987, O'Brien 1994). In North America, there are 19 species of voies, 4 of

which are of pest significance. They are the most prolific of all rodent species and probably the most important item in the food chain among secondary consumers (Corrigan 2001). Tree or shrub damage usually occurs under snow or dense vegetation. The bark is gnawed from small trees near the root collar and up the trunk to the snow surface (see Fig. 34.13A). Voles gnaw through small trees or shoots up to 6 mm in diameter. Some vole species also cause extensive damage to root systems and this damage may not be detected until spring, when it is reflected in condition of new foliage. Voles and other rodents thrive in no-till agricultural settings and cause a great deal of damage (Witmer et al. 2007). Voles can damage field and garden crops as well, and when vole populations are high, losses can be severe (Clark 1984, Marsh 1985a). They also are carriers of **baboon plague and tularemia**.

Vole populations are characterized by 3 levels: (1) low, (2) high, and (3) irruptive (Johnson and Johnson 1982). In North America, population peaks occur about every 4 years, although not in explosive numbers and not predictably (Johnson and Johnson 1982). Voles are active throughout the year. Their presence is most easily ascertained by searching for their runways and burrow systems. In orchards, these can be found by pulling the grass and other debris from the bases of trees. Gnawing on trunks and roots of trees is not as uniform as that of other rodents. Tooth marks can be at all angles, even on small branches, and may vary from light scratches to channels 3 mm wide, 2 mm deep, and 10 mm long. In hay crops, runways with numerous burrow openings, clipped vegetation, and feces can be detected in dense vegetation. **Damage management techniques** for voles include habitat modification (provision of alternative foods), exclusion, toxicants, and traps (snap traps).

Moles

There are 7 species of **moles** (representing 5 genera) in North America; 4 of these species have distributions restricted to the Pacific Northwest and West Coast of the United States (Yates and Pedersen 1982). Moles feed primarily on soil invertebrates, especially earthworms and grubs (insect larvae). Vegetation can comprise up to 20% of the diet of some species of moles. Although they damage crops and ornamentals, they are most detrimental to turf areas (Marsh 1996). They are active year-round. Voles and mice also use burrows of moles and can be responsible for some damage attributed to moles (Henderson 1994a).

Moles can usually be detected by mounds of soil brought up from extensive tunnels dug in search of food and by raised soil of surface burrows. Shallow tunnels of moles can be confused with those of pocket gophers, but moles typically leave volcano-shaped mounds composed of clods of soil and their burrow plugs are at the peaks of the hills. **Gophers** leave fan-shaped mounds with the burrow plug near the base of the mound (Henderson 1994a). Generally, go-

phers produce larger mounds than moles, but the Townsend's mole (*Scapanus townsendii*) can produce up to 4 mounds/day (Yates and Pedersen 1982). The burrowing activity of moles may reduce production of forage crops by undermining and smothering vegetation and by exposing root systems to drying. Forage production in pastures can be reduced 10–50% by burrowing activity (Yates and Pedersen 1982). Their surface burrows also can plug harvesting machinery and contaminate hay and silage. The burrowing activity of moles can extensively damage lawns and golf greens. **Damage management techniques** include habitat modification (soil compaction, flooding), exclusion, chemical repellents, insecticides (to reduce the moles' primary food source), fumigants, toxicants, and traps.

Pocket Gophers

Thirteen species of **pocket gophers** (*Geomys* spp., *Pappogeomys castanops*, and *Thomomys* spp.) occur in the United States. They can cause substantial damage to agricultural crops, lawns, rangeland, and tree plantings. Gophers feed primarily on underground portions of plants and trees. Root crops such as potatoes, sweet potatoes, beets, parsnips, turnips, and carrots are favorite foods, as are field crops such as alfalfa and clover (Marsh 1998). Damage is often undetected until a tree shows aboveground signs of stress, by which time the damage may be lethal. Pocket gophers also may damage plastic irrigation lines in agricultural settings, as well as underground pipes and cables (see Fig. 34.13B). In rangeland, soil disturbance and mound building by pocket gophers results in increased plant diversity, favoring annual and invasive species. They also can reduce the carrying capacity of rangeland for livestock. Gopher mounds can cause equipment breakage and increase wear of haying machinery. Furthermore, their burrows can cause substantial losses of irrigation water, especially in flood-irrigated crops (Marsh 1998).

Pocket gophers are a major impediment to reforestation in the western United States (Crouch 1986). They damage trees by stem girdling and cutting, root clipping, and exposing roots to drying (Case and Jasch 1994). In winter, pocket gophers often forage aboveground by tunneling through snow. Extensive aboveground girdling is easy to detect. Damage to roots may go unnoticed until seedlings fall over and become discolored (Nolte et al. 2000).

Fan-shaped soil mounds, in contrast to the conical mounds of moles, easily identify pocket gopher presence. Burrow entrances are typically plugged. Aboveground debarking damage caused by pocket gophers shows small tooth marks, differing from the distinct broader grooves left by porcupines and the finely gnawed surface caused by meadow voles. Gophers sometimes pull saplings and vegetation into their burrows. Gophers also fill some of their snow tunnels with soil, forming long, tubular "soil snakes" that remain after the snow melts (see Fig. 34.13C). **Damage management techniques** include habitat modification (flood irrigation,

crop rotation), cultural practices (plastic mesh cylinders to protect seedlings, protective coverings for pipes and cables), fumigants, toxicants, and traps.

Prairie Dogs

There are 5 species of **prairie dogs** (*Cynomys* spp.) in North America. The Mexican (*C. mexicanus*; endangered) and Utah (*C. utahensis*; threatened) prairie dogs are federally listed. Prairie dogs live in colonies that are easily identified by conical mounds around burrow entrances and by the presence of these highly visible rodents. Populations were reduced greatly by intensive control and conversion of habitat to agriculture in the early to mid-1900s. In recent years, populations have been expanding, commensurate with reduced control efforts.

Prairie dogs damage rangelands and pastures by clipping vegetation for food and nesting material and by clearing cover from the vicinity of burrows (Hygnstrom and Virchow 1994). Their activity not only reduces available forage, but also can alter species composition of vegetative communities in favor of forbs. Competition with cattle is minimal and, in some situations, beneficial effects of prairie dogs may offset competition. Thus, each conflict situation should be evaluated individually (Fagerstone 1981). Crops planted near prairie dog colonies can receive serious damage from feeding and trampling. In addition, damage to irrigation systems is common and **American badgers** (*Taxidea taxus*) digging for these rodents can cause even greater damage. The burrows and mounds created by prairie dogs can increase soil erosion and drainage of irrigation water, and cause damage to farm machinery.

Prairie dogs serve as a reservoir for **bubonic plague** (Hygnstrom and Virchow 1994) and are often responsible for periodic outbreaks (Witmer et al. 2003). Prairie dog colonies also provide habitat for other species such as the endangered black-footed ferret (*Mustela nigripes*). Reestablishment of black-footed ferret populations may be hampered by the occurrence of plague outbreaks (Hanson et al. 2007). It is a violation of federal law to poison a prairie dog town when ferrets are present (Hygnstrom and Virchow 1994).

In recent years, prairie dogs have thrived in urban areas that were historically prairie dog habitat. Damage in these environments includes degradation of community open space, clipping of landscape vegetation, and encroachment into residential yards. Populations in urban areas can increase the probability of bubonic plague transmission to pets. **Damage management techniques** include habitat modification (e.g., deferred grazing), exclusion, fumigants, toxicants, traps (foot-hold and Conibear), and shooting.

Rabbits and Hares

Rabbits and hares (*Lepus* spp.; family Leporidae) can damage or destroy landscape plantings, gardens, agricultural crops, and rehabilitated rangeland. In winter, leporids may strip

bark from and debud fruit trees, conifers, and other trees and shrubs (Craven 1994). Populations of hares show large fluctuations and, during peak densities, hares can severely damage vegetation and compete with livestock for forage. Stems clipped by rabbits and hares have a clean, oblique, knife-like cut. Rabbits and hares usually clip stems ≤ 6 mm in diameter at a height not > 50 cm above the ground. Repeated clipping will deform seedlings. Leporids can often be observed at damage sites along with their tracks, trails, and droppings.

Rabbits are known vectors of **tularemia**, a zoonotic disease, and they may carry larvae of several ascarid roundworms that can produce disease if uncooked, infected meat is ingested by humans (Davidson and Nettles 1997). **Damage management techniques** include rabbit "drives" or "roundups," use of ferrets, habitat modification, exclusion, chemical repellents, traps, snares, and shooting (Smith et al. 2007).

Tree Squirrels

Tree squirrels can be grouped into 3 categories: (1) large tree squirrels (gray [*Sciurus carolinensis*], fox [*S. niger*], and tassel-eared [*S. aberti*]), (2) pine squirrels (red and Douglas), and (3) flying squirrels (northern [*Glaucomys sabrinus*] and southern [*G. volans*]; Jackson 1994b). Squirrels eat plants and fruits, dig up newly planted bulbs and seeds, strip bark and leave from trees and shrubs, invade homes, and consume bird eggs (Hadidian et al. 1987, Jackson 1994b). Squirrels also can cause problems by traversing power lines, gnawing on them, and shorting out transformers.

Squirrels often can be observed at the damage site. Damage to conifers is indicated by green, unopened cones scattered on the ground under mature trees and by accumulated cone scales and "cores" at feeding stations. Bark stripping can be observed in trees and bark fragments are often found on the ground, as are the tips of twigs and small branches. These activities may interfere with natural reseeding of trees that are important to forestry, particularly in ponderosa pine (*Pinus ponderosa*) forests, where pine squirrels may remove 60–80% of the cones in poor to fair seed years (Jackson 1994b). **Damage management techniques** include cultural practices (trimming limbs near buildings and transformers), exclusion, frightening devices, chemical repellents, toxicants, traps (Conibear, foothold, and live traps), and shooting.

Woodrats

Woodrats, also called pack rats, brush rats, or trade rats, are attracted to human food supplies in buildings and will remove small objects such as utensils and other items, sometimes leaving sticks or other objects "in trade." There are 9 species of woodrats in the United States, several of which have become significant pests in suburban and semirural developments in the Southwest (Corrigan 2001). They often

construct conspicuous stick houses in cabins, unused vehicles, rocky outcroppings, or in upper branches of trees (Marsh and Howard 1982, Salmon and Gorenzel 1994). They will shred mattresses and upholstery for nesting material.

Woodrats are agile climbers and consume fruits, seeds, and green foliage of herbaceous and woody plants. They clip small branches and strip and finely shred patches of bark for their nests. Their damage may be confused with that of tree squirrels and porcupines; however, woodrats leave a relatively smooth surface with a few scattered tooth marks and tend to litter the ground beneath the tree less than tree squirrels. Woodrats have been involved in epizootics of **plague** and have been infected with **tularemia**. At least 6 species of woodrats have been identified as reservoirs of **trypanosomes** (parasitic blood-infesting protozoa) that cause **Chagas disease** (Corrigan 2001). Some subspecies of woodrats are endangered; therefore, one should check local regulations before undertaking control efforts. **Damage management techniques** include exclusion, chemical repellents, toxicants, traps (snap and live traps), and shooting.

Commensal Rodents

The 3 species of **commensal rodents** (those that live primarily around human habitation) are Norway rats (*Rattus norvegicus*), roof or black rats (*R. rattus*), and house mice. These omnivorous rodents consume millions of bushels of grain each year in the field; on the farm; in the grain elevator, mill, store, and home; and in transit. They also waste many more millions of bushels by contamination. One rat can eat approximately 9–18 kg of feed/year and probably contaminates 10 times that amount with its urine and droppings (Timm 1994a, b). Pimentel (2007) estimates the number of rats on farms in the United States at 1.5 billion, causing damage in excess of \$27 billion annually.

Besides consuming plant products, commensal rodents feed on poultry chicks and occasionally attack adult poultry, wild birds, newborn pigs, lambs, and calves. In buildings and vehicles, rodents gnaw electrical wires, creating a serious risk to human safety (Corrigan 2001) and sometimes starting fires. Their gnawing also causes considerable property damage. Extensive damage to foundations and concrete slabs sometimes results when rats burrow under buildings. Burrowing into dikes and outdoor embankments causes erosion. Health departments annually report hundreds of human babies bitten by rats. Many viral and bacterial diseases are transmitted to humans by rodent feces- and urine-contaminated food and water. Among the diseases, rats may transmit to humans or livestock are **plague**, **murine typhus**, **leptospirosis**, **trichinosis**, **salmonellosis**, and **ratbite fever**.

Signs of commensal rodents include gnawing, droppings, tracks, burrows, and darkened or smeared areas along walls where they travel. Reviews of problems caused by these species and methods of control are provided by Timm (1994a, b), Hygnstrom and VerCauteren (1995), and Corrigan (2001).

Damage management techniques include tracking powder, habitat modification, cultural practices (sanitation), exclusion, fumigants, toxicants, and traps (snap and multiple-catch traps).

Management Techniques

There are 2 general categories of control related to rodents and other small mammals: **nonlethal** and **lethal**. Many traditional methods of wildlife-damage management are lethal; however, these methods are increasingly being questioned by society based on humaneness and target specificity. Presently, we lack ability to alleviate many wildlife damage problems in effective and economical ways using only nonlethal techniques (Conover 2002). Wildlife researchers specializing in damage management are expending considerable effort to develop nonlethal means to reduce damage. The following section briefly reviews control techniques commonly used to manage populations of rodents and small mammals. An **Integrated Pest Management (IPM)** approach is recommended for control of rodents and other small mammals. The IPM concept favors timely and strategic incorporation of a combination of cost-effective control techniques to reduce the impact of species on valuable resources.

Habitat Modification and Cultural Practices

All animals are dependent on food and shelter; therefore, elimination of one or both of these requirements will force them to move from the immediate area. This method of control, where practical, is the most desirable and usually has the most permanent effect in reducing small mammal damage. However, other species often are dependent upon the same habitat. **Modifications of the habitat** can result in greater adverse effects to desirable nontarget species and natural communities than careful use of a registered toxicant or other control tool. Modifications also can create situations that contribute to other species becoming pests.

Many rodents and small mammal pests can be discouraged from using areas by removal of brush and woodpiles, weeds, and other debris. Commensal rodent control can be greatly facilitated by removal of harborage, garbage, and refuse. Squirrel interference with power transformers may be reduced if vegetation near power poles is managed (Hamilton et al. 1987). Mountain beaver populations in silvicultural areas may be decreased by removing surface shelter such as stumps, logs, and brush piles (Cafferata 1992). High populations of muskrats in sugarcane are associated with debris remaining in fields after harvest (Steffen et al. 1981).

Davis (1976) reported that pine vole damage in an apple orchard was reduced by mowing 3 times/year, clearing vegetation from under the trees, removing pruned branches, restricting distribution of fertilizer and, after harvest, inspecting and cleaning vulnerable parts of the orchard. Control of pine voles with anticoagulant baits was enhanced in apple orchards cultivated 2 or 3 times/year (Byers 1976). Byers

(1984), however, found that **cultural controls** (combinations of mowing, cultivation, and herbicide application) were much more expensive than application of **toxic baits** and offered no advantages in vole control. Evaluation of large-scale use of **diversionary foods** to reduce vole damage provided promising results (Sullivan and Sullivan 2008).

Various **mechanical methods** have been developed to prevent beaver from stopping water flow through culverts (Roblee 1987). Water levels behind beaver dams can be manipulated by installing a perforated pipe or a 3-log drain (Miller and Yarrow 1994) through the dam. Muskrat damage to farm-pond dams can be reduced by maintaining a 3:1 slope on the water side of the dam, a 2:1 slope on the outer face, and a top width of 2.4 m (Miller 1994).

Provision of **alternative foods** can reduce conifer seed loss to mice in forest regeneration projects (Sullivan and Sullivan 2008) and may be useful in reducing loss of agricultural crop seedlings in no-tillage fields (Hygnstrom et al. 2000) and orchards (Sullivan and Sullivan 1988). Pocket gopher infestations in logged areas can be reduced by prompt regeneration and minimal site preparation. Selective cutting, when feasible, can be used in areas with high potential for gopher infestations (Crouch 1986). Use of insecticides to reduce numbers of soil invertebrates can protect turf from nine-banded armadillos (*Dasypus novemcinctus*) and moles, but damage may initially increase due to increased food-searching by animals already present (Henderson 1994a).

Exclusion

Exclusion involves installation of barriers that prevent access by pest species into structures or areas, or elimination of their physical contact with specific objects. Rodent-proofing of structures is achieved most economically if incorporated into construction plans. Corrigan (2001) provides detailed suggestions on how to accomplish rodent-proof construction. Basically, openings or sites where rodents might create openings are protected with wire mesh, sheet metal, or concrete, providing long-term protection. **Steel sheathing** also has been incorporated into underground power- and telephone-line wiring to provide protection from gnawing rodents.

Exclusion is a necessary part of an effective program to remove bats from structures. Final closure of entrances to the structure should not be made until all young have reached the flight stage. At that time, these openings can be closed with a **1-way door** that permits bats to leave the structure, but prohibits reentry.

In small orchards, rodent and rabbit damage can be eliminated by wrapping trees with hardware cloth or burlap that is buried 5 cm deep around the tree base. **Plastic seedling protectors** will protect conifer seedlings from rodents and rabbits. These plastic net-tubes are placed over seedlings at planting. Some allow branches to grow through the netting and provide protection for the terminal bud for 3–5 years as the terminal leader grows through the tube. A 0.6-m-wide

expandable metal band placed around tree trunks 2 m above the ground will keep squirrels out of individual trees. Branches should be trimmed within 2 m of the ground or buildings. **Fences** made of 1.2–2.5-cm-mesh net wire 0.7–1.0 m high can protect small areas against nonclimbing rodents and small mammals. Lower edges of fences should be buried with an "L" shape on the outside of the fence to prohibit burrowing under the fence. Both **visual and physical barriers** are commonly used in attempts to minimize prairie dog town expansion in urban settings, though efficacy is often minimal and costs range from \$1/m to \$5/m and \$30/m to \$60/m, respectively (i.e., Merriman et al. 2004, Foster-McDonald et al. 2006, Witmer et al. 2008b).

Frightening Devices

Frightening devices may deter rodents and small mammals from localized areas for short periods. These devices are designed to frighten animals by targeting their visual or auditory senses. **Visual repellents** (e.g., eyespots, predator effigies, Mylar) were designed to repel birds, although some of these visual devices also may affect mammals (Mason 1998). **Sonic devices** include distress calls, pyrotechnics (e.g., live ammunition, shell crackers, firecrackers), propane cannons, and sirens. Numerous **ultrasonic devices** are available commercially, but (like most frightening devices) are ineffective in alleviating damage over the long term (Shumake 1997). Limited research with frightening devices has been conducted on rodents and small mammals (i.e., Koehler et al. 1990).

Biological Management

Exploration into methods of **biological management** has received increased attention and evaluation (Hygnstrom et al. 1994). A variety of techniques, including agents of **disease or predators**, to control populations of small mammals have been evaluated. In the 1950s, *Myxoma* virus was used to control United Kingdom rabbit populations, resulting in 99% mortality (Lees and Bell 2008). Rabbit haemorrhagic disease has been viewed as a cost-effective tool in the successful reduction of rabbit populations in Australia (Vere et al. 2004, Henning et al. 2005). Various other **pathogens** including **protozoa** (Jäkel et al. 2006), **bacteria** (Kaboodvandpour and Leung 2007), and **viruses** (Hood et al. 2000) have been examined as potential tools for mammalian pest control with variable results. Protecting rice crops by applying *Sarcocystis singaporensis* protozoa was determined to be more cost effective than applying zinc phosphide (Jäkel et al. 2006). Although agents of disease may be an effective tool in population reduction, they may have adverse effects on regional biodiversity or even widespread ecological effects that must first be assessed. Species specificity also is an underlying concern of using disease-causing agents as a tool, because susceptibility may be unknown.

Use of predatory species to alleviate damage by pest species has been more widespread with insect pests, though

also has application with birds and mammals. **Ferrets** (*Mustela putorius furo*) have been used effectively in the capture of rabbits, though often for recreational purposes. Using ferrets for large-scale rabbit reductions in some areas has resulted in the establishment of feral ferret populations, which can result in widespread damage as well. **Mongoose** (family Herpestidae) have historically been used to control rats in sugarcane fields around the world, with questionable success. On the Hawaiian Islands, and other islands, mongoose introductions for rat control backfired and resulted in the demise of many species of birds, lizards, frogs, and snakes (Pitt and Witmer 2006). The common domestic **farm cat** (*Felis catus*) was traditionally employed for its abilities in **rodent control**, though also proficient in capture of nonpest species such as songbirds. The deployment of domestic cats was actually conducted in 1960 on Borneo in attempts to control rodent populations (Harrison 1965). The installation of **raptor perches** adjacent to areas in which rodent control is desired provides additive reduction in rodent numbers (Fig. 34.14; Hall et al. 1981, Murua and Rodriguez 1989, Witmer 2009).

Fertility Control

The use of **fertility control** measures, including the use of chemical and immunological agents to provide reproductive inhibition on rodents and other small mammals, has been the focus of several studies (Mauldin and Miller 2007). Development of an effective method of delivery for the agent to rodents or small mammals is a challenge in itself. For example, Nash et al. (2007) achieved nearly 50% reduction in prairie dogs with the use of an oral contraceptive delivered in enticing baits for 10 consecutive days in the field. Additionally, viral-vectored immunocontraceptives are in development, and may eventually be registered for a variety of pest species (Hood et al. 2000). As with any application of fertility control measures on pest species, an initial population reduction action would be the first step. In a case with

many commensal rodents, invasive species, and other pest species the desire to sustain a population may not be the goal; thus, the development of a lethal tool may be more appropriate.

Repellents

Several compounds have been registered for use as small-mammal **repellents** (Jacobs 1994); however, definitive efficacy data for most are lacking (Mason 1998), as is information on why some chemicals repel offending animals. Repellents are most effective when applied directly to foods with the intent of reducing consumption (Mason 1998). **Chemical repellents** for rodents are grouped into 3 categories: (1) **sensory irritants**, (2) **semiochemical odors** (e.g., predator urines), and (3) those that produce **conditioned taste-avoidance** behavior (Clark 1998, Mason 1998).

Specific semiochemicals found in predator excreta apparently induce fear and, thus, area avoidance by certain prey species. For example, Swihart and Picone (1994) achieved a 98% reduction in gnawing by woodchucks on apple trees through the application of bobcat (*Lynx rufus*) urine. Sullivan and Crump (1984) also had positive results in the use of predator scents to deter hare feeding on lodgepole pines (*Pinus contorta*). Sullivan et al. (1988) hypothesized that a reduction in damage by voles following the application of **predator scents** may have been due, in part, to increased predator activity in response to the application.

Use of some area repellents, such as naphthalene or paradichlorobenzene, in structures is often limited because the vapors cannot be prevented from permeating areas occupied by people. The efficacy of repellents applied to plants or seeds are affected by availability of natural foods and ability to withstand weathering. **"Bitter" chemicals** (e.g., thiram, denatonium benzoate, denatonium saccharide, sucrose octaacetate) are not necessarily perceived by animals as such, and are not inherently repellent to herbivores. Commercially available repellents for deer (Mason et al. 1999) and experimental formulations (Figueroa et al. 2008) emitting sulfur odors and volatile fatty acids effectively deter rabbits and potentially other mammalian species from feeding on tree seedlings.

Repellents that act by inducing taste-avoidance behavior function by producing smell or taste aversions, or gastrointestinal malaise. Those claimed to work because they are perceived as bitter by humans probably are either ineffective or are paired with some other compounds that cause illness or distress (Mason 1998, Nolte 1999). Some repellents create a burning sensation (e.g., capsaicin). **Capsaicin** encased within utility cables provided protection from gnawing by pocket gopher and rats (Shumake et al. 1999, 2000). Various taste sensations (bitter, sour, sweet, etc.) affect animals differently, or may have no effects. **Thiram**, the most widely used taste repellent, can be applied to trees, tree seeds, seedlings, bulbs, and shrubs to protect them from rodents and moles.



Fig. 34.14. Fabricated raptor perches constructed to facilitate predation of rodents by raptors in areas where rodent population-management tools are needed. Photo by G. Witmer.

Thiram should not be used on plant parts eaten by humans or domestic animals. Fruit trees must be sprayed only in the dormant season. Innovative work into the stimulation of satiation receptors has potential to minimize damage caused by rats (Cotterill et al. 2005).

Fumigants

Fumigants registered for rodent control include smoke-producing gas cartridges, aluminum phosphide, chloropicrin, and methyl bromide (Corrigan 2001). When inhaled, fumigants are lethal and are used to kill burrowing mammals. When fumigants are used, all burrow openings should be closed after introduction of the pesticide. **Active ingredients** in gas cartridges are a combination of sulfur, nitrate, charcoals, or phosphorous compounds, which, when ignited, produce carbon monoxide and other gases. These gases asphyxiate rodents in their burrows (Corrigan 2001).

Aluminum phosphide is a fumigant available in tablets or pellets that produces toxic phosphine gas when exposed to atmospheric moisture, and this gas is flammable or explosive at some concentrations. **Chloropicrin** is typically used as an additive to fumigants to provide an exposure warning (like sulfur is added to natural gas). Its only other registered rodent uses are in empty grain and potato storage bins to control rats and mice. **Methyl bromide**, because it has been documented to deplete atmospheric ozone (Ristaino and Thomas 1997), will not have its registration renewed. Hygnstrom and VerCauteren (2000) evaluated effectiveness of 5 fumigants (aluminum phosphide, gas cartridge, methyl bromide, chloropicrin, and a methyl bromide-chloropicrin mixture) for managing prairie dogs; all reduced burrow activity by 95–98%. Jacobs (1994) provides information on specific fumigants.

Toxicants

Toxicants are the most common method used to control damage-causing populations of rodents and other small mammals. Toxicants require little labor and can kill large numbers of animals over large expanses of land (Pascal et al. 2008). Damage reduction is the goal of any control program and must be the final measure of efficacy. Efficacy of a control program may be increased by using several toxicants in combination or by periodically alternating those used. This strategy aids in avoiding development of resistance to the primary toxicant (Marsh 1988).

One disadvantage of toxicants is that they usually are not species-specific (Conover 2002). Potential hazards to nontarget species must be considered when toxicants are used. Hazards associated with use of a toxicant are not necessarily related to toxicity of the compound, but are more often associated with how they are applied. Hazards to nontarget wildlife can be reduced by properly selecting toxicants, bait composition and formulation techniques (including bait color, size, shape, texture, and hardness), and bait delivery systems

(Marsh 1985b). Some toxicants may be absorbed by plants and pose a risk to herbivores (Conover 2002). To reduce environmental hazards, the EPA closely regulates registration and monitors risks of toxicants (Erickson and Urban 2004), approving only those that decompose rapidly and do not pose a significant threat to other species. Above- and below-ground carcass searches can be conducted to evaluate efficacy and nontarget mortalities of the management effort (Witmer et al. 1995, VerCauteren et al. 2002b).

Toxicants are classed as either anticoagulants or non-anticoagulants. Historically, anticoagulants were considered multidose or chronic toxicants, and nonanticoagulants as single-dose or acute toxicants. New-generation anticoagulants, however, can be effective in a single feeding and some new nonanticoagulants need to be ingested by individuals of the target species over several days (Marsh 1988). **Baits** come in a variety of forms including food, block, pellets, loose meal, seeds, packets, liquids, tracking powder, and non-toxic monitoring blocks.

Numerous toxicant formulations are registered for use in commensal rodent control around farm buildings and in noncrop areas; however, fewer are available for use in crops. Development of registrations for in-crop use of toxicants, particularly anticoagulants, is a high-priority research area. However, use of toxicants is expected to decline as alternative methods of reducing damage are developed (Fagerstone and Schafer 1998).

Anticoagulants are chemicals that disrupt the normal clotting process of blood. Death in poisoned rodents results from internal hemorrhaging and damage to capillaries (Corrigan 2001). There are 2 classes of anticoagulants, first-generation (multiple-dose) and second-generation (single-dose). First-generation anticoagulants typically require several consecutive doses to kill, while second-generation anticoagulants cause death after a single dose. First-generation anticoagulants generally require ingestion for 3–14 consecutive days to be effective. **Bait shyness** is generally not a problem because animals do not associate ill effects with bait consumption. However, bait delivery procedures must consider the need for making toxicants available over several consecutive days. Warfarin was the first, most widely used, of the “rat poisons” for many years (Corrigan 2001). Despite a popular misconception that warfarin is no longer used because mice and rats have developed a physiological resistance to it, in actuality, its patent has expired and newer pesticides more profitable for manufacturers have displaced the older pesticides. **Physiological resistance** to warfarin and other first-generation anticoagulants is actually a minor problem. Such resistance usually only occurs after continuous use at the same site for several years and can be overridden by switching temporarily to another rodenticide, such as zinc phosphide. Nevertheless, manufacturers and marketers of the second-generation anticoagulants, which are effective against rodents resistant to the first-generation compounds, have

touted this effectiveness against resistant rodents in their sales pitch. Chlorophacinone and diphacinone are other first-generation anticoagulants still widely used, but neither is effective against rats resistant to warfarin. Vitamin K is an antidote for first-generation anticoagulants.

The **active ingredients** brodifacoum, bromadiolone, and difethialone comprise the most popular second-generation anticoagulants used in the United States (Corrigan 2001). These anticoagulants are highly toxic to rodents and a single feeding on baits with an active ingredient concentration as low as 0.005% can result in death (Marsh 1988). Currently, all second-generation anticoagulants are effective against warfarin-resistant rodents.

Anticoagulants can be obtained in prepared baits or purchased as concentrates for mixing with fresh bait. Baits should be placed where rodents feed, drink, or travel. For anticoagulants that require multiple ingestions, bait stations purchased from pesticide supply houses or constructed from wood or metal, are particularly useful in protecting the bait from weather and nontarget species (Fig. 34.15). Some baits come in packets that are gnawed open by rodents and others are available in moisture-resistant paraffin blocks. Several anticoagulants are registered for use in **tracking powders**, which are dusted into burrows and along runways where house mice or Norway rats travel. Rodents ingest the anticoagulant by licking the toxic dust from their feet and fur.

Toxicants with different modes of action provide an obvious answer to anticoagulant resistance. The 3 most common nonanticoagulant baits used in the structural pest management industry are zinc phosphide, cholecalciferol, and bromethalin. **Zinc phosphide** is an effective, acute toxicant that has been in use for >50 years with minimal nontarget

hazards (to humans and other nontarget species), though several instances of unintentional intoxication in food-stressed turkeys have been documented recently (Poppenga et al. 2005). A key to success with zinc phosphide is prebaiting to establish a feeding routine. For some species of field rodents, such as **prairie dogs**, it is the only pesticide currently registered for use (Fagerstone and Schafer 1998). Hygustrom et al. (2000) found that zinc phosphide pellets applied in-furrow at planting reduced corn yield loss and zinc phosphide has since been registered for this use. Hygustrom et al. (1994) also provides species-specific baiting strategies using zinc phosphide. **Cholecalciferol** (vitamin D3) is both a single- and multiple-feeding toxicant effective on commensal rodents (Marshall 1984). No secondary hazards have been associated with its use (Marsh 1988). **Bromethalin** also is effective on rats, including those resistant to warfarin.

Strychnine is another nonanticoagulant acute rodenticide used to control pocket gopher and some ground squirrel populations to reduce damage to forest seedlings, agricultural crops, and home landscaping (Fagerstone and Schafer 1998). Due to regulatory and court actions, its former widespread use has now been restricted to underground applications (in pocket gopher and ground squirrel burrows).

Removal

Live traps are often used to capture mammals of all sizes without harm (Fig. 34.16). They are an excellent option to use in residential areas or to relocate rodents and other small mammals causing damage. Various homemade designs can be constructed of wire mesh or wood, or wire mesh and plastic models can be purchased commercially. Certain models can be used to capture a variety of species, while others are species-specific. Some designs have doors at both ends, permitting visibility through the trap, thereby reducing trap shyness. Suggested baits, which depend on the species being trapped, include apple slices, sunflower seeds, peanut butter, and rolled oats. **Multiple-capture live traps** for nutria have potential to increase trapping efficiency and provide another tool to gain control of burgeoning invasive species (Witmer et al. 2008a).

Foothold traps are manufactured in several sizes and designs (Fig. 34.17). Traditional foothold traps are commonly used for beaver, muskrat, and nutria control, while smaller sizes are used to capture tree and ground squirrels, rats, and marmots. Use of foothold traps, body-gripping traps, and snares is controversial; however, when properly used they are effective and valuable wildlife management tools. Some states prohibit their use, whereas others permit only traps with padded or offset jaws. Like other types of traps, there is potential to capture nontarget species. This danger can be lessened by using proper trap sizes, pan tension devices, breakaway mechanisms, species-specific baits, and selecting trap locations that target the habits of the species being trapped (Conover 2002).



Fig. 34.15. Bait station and packet of anticoagulant bait used for rodent control. Photo by K. VerCauteren.



Fig. 34.16. Live traps come in a variety of sizes and styles for almost any mammalian species. Photo by M. Lavelle.

Body-gripping traps, primarily **Conibears** (see Fig. 34.17E), are used in water sets for beaver, muskrat, and nutria. Manufactured in a variety of sizes, they have the humane feature of killing quickly. These traps have a pair of opposing, heavy-gauge rectangular rods that close like scissors when triggered, killing the animal with a quick body blow. Conibear traps are lightweight and easy to use. They can be placed at entrances of burrows and lodges and in dams, runs, and slides. Care should be taken when large Conibear traps are used due to the potential hazard to pets, children, and nontarget species. Some states prohibit the use of dry-land sets.

Body-gripping traps also are available for moles and pocket gophers. For moles, the trap is placed over a section of the burrow that has been intentionally collapsed or compressed by the broad trap pan. The trap is activated when a mole, traveling the runway, pushes up on the compressed roof, trips the trigger pan, and is caught by the loops or scis-

sor action of the jaws. The **harpoon trap** is set in a similar fashion, but a spring-loaded harpoon spears the mole. For gophers, traps are placed into the exposed laterals or main tunnels of the burrow system. The openings can then either be left exposed or covered.

Snap traps are most commonly used for controlling rats and mice, and are used regularly in houses and other buildings. Advantages to using snap traps include reduced danger to children or pets compared to some chemicals, easy recovery of killed animals, and no contaminants. Obstacles such as boxes or boards can be used to direct rodents to traps. **Preferred baits** include a mix of peanut butter and rolled oats, a small piece of bacon or apple, or a raisin. Snap traps can be used outdoors to capture small field rodents when only a few animals are involved, or to capture animals for identification or population ecology studies.

Beaver can be captured as effectively with snares as with Conibear or foothold traps (Weaver et al. 1985). **Snares** cost and weigh less than traps. Depending on whether the snare has a **stop-lock device** to restrict tightening, the behavior of the captured animal and the length of time it has been held, as well as the part of the anatomy that is being held, the animal may or may not die before it can be found and released. Snares also are effective in controlling small populations of rabbits. Animals must be traveling a well-defined trail or using a specific entrance such as a hole in a fence. Snares are made of a loop of lightweight wire or cable incorporating a **locking device** to prevent the animal from backing off the tension in the cable. Snares can be set to kill the captured animal or to hold it by the leg or neck. Research is being conducted to make snares more species-selective. State wildlife regulations should be checked to ascertain legality of snare usage.

Shooting can be a selective method of eliminating individual pest mammals. Small-bore shotguns, rifles, and air guns are effective firearms. Some animals can be shot most effectively at night by using a spotlight with a red lens or night-

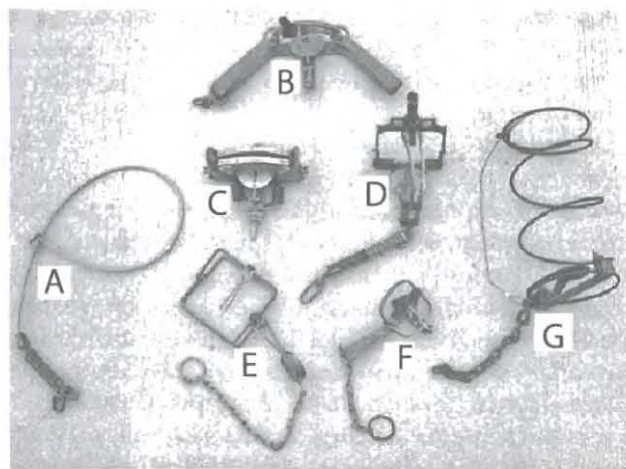


Fig. 34.17. Examples of several types of traps, including foothold (B, C, D, and F), snares (A and G), and body-gripping trap (E). Photo by M. Lavelle.

vision equipment. Shooting is especially useful in controlling animals with low reproductive rates, such as porcupines. Local wildlife codes must be reviewed before shooting is used. Shooting at night, in particular with a spotlight, is not legal in some states.

CARNIVORES AND OTHER MAMMALIAN PREDATORS

Damage Assessment

Depredations of livestock by mammalian predators have been a concern to livestock producers for many centuries. In the United States, 224,200 sheep and lambs were estimated to have been lost to predators in 2004 (Agricultural Statistics Board 2005). Losses to predators represented 37% of total losses to all causes and resulted in loss of \$18 million to farmers and ranchers. In 2004, depredations of sheep and lambs were mainly caused by coyotes (60%), dogs (*Canis lupus familiaris*; 13%), mountain lions (*Puma concolor*; 6%), and bears (*Ursus arctos horribilis* and *U. americanus*; 4%). Cattle and calf losses to predators in the United States totaled 190,000 head during 2005 with an estimated loss of \$92.7 million (Agricultural Statistics Board 2006). Losses to predators accounted for only 5% of total losses. **Coyotes** caused 51% of predator losses to cattle and calves, followed by **dogs** (11%). Losses of poultry to predators, although not well documented, also are believed to be substantial (Andelt and Gipson 1979). Not only do predators directly kill livestock, but changes in livestock behavior (Kluever et al. 2008) also should be considered.

Predation by coyotes, wolves (*Canis lupus*), bears, and mountain lions can be a significant mortality factor for many ungulate species, mainly white-tailed deer, mule deer, black-tailed deer (*O. h. columbianus* and *O. h. sitkensis*), moose, caribou (*Rangifer tarandus*), and elk (*Cervus canadensis*; Linnell et al. 1995, Ballard et al. 2001). Predation on neonatal ungulates with losses >50% of the fawn cohort is commonly documented, especially in areas with coyotes (Barrett 1984, Hamlin et al. 1984, Whittaker and Lindzey 1999). Whether predation is a factor regulating ungulate populations, and whether predator control can enhance ungulate populations, continues to be a matter of debate among scientists (Connolly 1978, Messier 1991, Sinclair 1991, Boutin 1992, Ballard et al. 2001) and remains controversial with the general public (Kellert 1985, Andelt 1987).

Predation by red foxes (*Vulpes vulpes*), skunks (genera *Conepatus*, *Mephitis*, and *Spilogale*), raccoons (*Procyon lotor*), and mink (*Mustela vison*) can be a major source of mortality to waterfowl (Sovada et al. 2001, Pearse and Ratti 2004), grouse (subfamily Tetraoninae; Hewitt et al. 2001, Schroeder and Baydack 2001), ring-necked pheasant (*Phasianus colchicus*; Riley and Schulz 2001), quail (subfamily Odontophorinae; Rollins and Carroll 2001), Neotropical migrant songbirds (Heske et al. 2001), and rare or endangered species

such as sea turtles (family Cheloniidae; Ratnaswamy et al. 1997, Engeman et al. 2006), forest mammals (Dexter and Murray 2009), and rare birds (Hartman et al. 1997). Predation may affect nest success, juvenile survival, and adult survival. The **red fox** is possibly the most serious predator of waterfowl because it can kill nesting hens as well as destroy eggs (Sargeant et al. 1984). Nest predation by **raccoons and skunks** also can impact nesting waterfowl, as well as threatened and endangered bird species.

How predators impact other predators is a topic of growing interest (Johnson et al. 1996). Many larger predators directly kill smaller competing carnivores, some of which are endangered species or species of concern; see Johnson et al. (1996) and Creel et al. (2001) for reviews on **interspecific competition** and intra-guild predation. For example, coyotes killing swift foxes (*V. velox*; Sovada et al. 1998, Schauster et al. 2002) and kit foxes (*V. macrotis*; White and Garrott 1999, Cypher et al. 2000) has been well documented, with this level of mortality possibly causing population declines or limiting recruitment (White et al. 2000, Kamler et al. 2003, Karki et al. 2007). Recent reintroductions of wolves into the northern Rocky Mountains has brought about changes in coyote abundance (Berger and Gese 2007) and a subsequent shift in trophic interactions resulting in an increase in pronghorn (*Antilocapra americana*) fawn survival (Berger et al. 2008). **Indirect effects**, such as spatial avoidance or segregation, temporal separation, and resource partitioning, also are influential on the distribution and dynamics of smaller sympatric predators (Creel et al. 2001, Gosselink et al. 2003, Thornton et al. 2004). Understanding the interactions between competing predators will continue to be important, particularly in areas where increased human development will limit available habitat (Creel et al. 2001).

Actually witnessing a predator killing a prey item is rare. Therefore, an accurate assessment of a predation event requires careful observational skills (O'Gara 1978a, Bowns and Wade 1980). O'Gara (1978a), Wade and Bowns (1982), and Acorn and Dorrance (1998) provide a review of examination and identification of predators involved in depredation events. In general, upon arrival at a depredation site, personnel should approach the site carefully, and be sure not to trample tracks, feces, blood, vegetation, or other evidence that may assist in identifying the cause of death and the predator involved (if it is predation). **Signs of predation** and the possible predator involved should be searched for on the prey item and around the kill site. Collection of salivary DNA samples from the attack wounds can be used to identify the responsible predatory species, as well as the sex and identity of the individual animal (Blejwas et al. 2006). These sterile samples should be collected prior to handling or skinning the carcass to prevent sample contamination. Extensive **hemorrhaging** usually is characteristic of predation. If predation is suspected, skinning the carcass (particularly around the neck, throat, and head) may provide clues

to the predator involved by examination for subcutaneous hemorrhage, tissue damage, and the size, spacing, and location of tooth marks (O'Gara 1978a, Wade and Bowns 1982). Hemorrhaging occurs only if the skin and tissue damage occurred while the animal was still alive. Animals that die from causes other than predation normally do not show external or subcutaneous bleeding, although bloody fluids may be lost from body openings (O'Gara 1978a, Wade and Bowns 1982). The cause of death is best evaluated if the carcass is examined when fresh. **Tracks and scats** alone are not proof of depredation or of the species responsible, only that a particular predator is in the area. Other signs associated with a depredation event include nervous or alert livestock, injured livestock, or females calling or searching for young (Acorn and Dorrance 1998). Thus, all evidence must be considered to ascertain whether the death was due to a predator and the predatory species responsible. Many predators will scavenge carcasses; hence, scavenging should not be confused with predation. Although not tested for this purpose, scent-matching dogs (Smith et al. 2003) hold promise as a method to detect and identify the predator species at a kill site, and even to identify the individual animal (Kerley and Salkina 2007).

Identification of Species Damage

Badgers

Badgers are opportunistic feeders, preying primarily on mice, prairie dogs, marmots, pocket gophers, ground squirrels, and occasionally on rabbits (especially young; Messick 1987, Lindzey 1994). Badgers destroy nests of ground-nesting birds and occasionally kill small lambs and poultry. Their burrows in a field may slow harvesting or cause damage to machinery, and their digging can damage earthen dams or dikes (Lindzey 1994, VerCauteren et al. 2005a). Badger tracks appear similar to coyote tracks, but badger tracks appear to be pigeon-toed and impressions from the long toenails are apparent under most conditions (Murie 1954). Signs of digging near prey remains may be the best evidence of badger activity. **Damage management techniques** include fencing, frightening devices, traps (foothold), snares and shooting.

Black and Grizzly Bears

Conflicts with bears occur when they prey on livestock, feed on field crops, destroy beehives, or become a nuisance around campgrounds, cabins, landfills, and garbage dumps (Hygnstrom 1994, Jonkel 1994, Baruch-Mordo et al. 2008). Bears usually kill by biting the neck or by slapping the victim, leaving a mauled and mutilated carcass (O'Gara 1978a, VerCauteren et al. 2005a); the neck may be broken (Acorn and Dorrance 1998). Bears will trample the vegetation and often vomit or defecate near the carcass. Large prey items are usually opened ventrally and the heart and liver consumed (Bowns and Wade 1980); the udder of lactating females may be consumed. The intestines often are spread

around the site, and the animal may be partially skinned where the carcass is fed upon (VerCauteren et al. 2005a). Sheep and goats may be consumed almost entirely, with only the rumen, skin, and large bones remaining (Acorn and Dorrance 1998). Bears use their feet while feeding, and do not slide the prey around (O'Gara 1978a). However, if the prey is killed in the open, the carcass may be dragged to a secluded spot before or after initial consumption (Acorn and Dorrance 1998).

Brown bears have a feeding and killing pattern similar to that of black bears (Jonkel 1994), but they usually cover their prey after the initial feeding, whereas black bears rarely cover the prey item (Acorn and Dorrance 1998). Cattle are usually killed by a bite through the back of the neck and large prey often has claw marks on the flanks or hams. The back of an ungulate is often broken in front of the hips where the bear pushes the animal down. Young calves are sometimes bitten through the forehead. Sheep may stampede at the onset of a bear attack and injure or kill themselves by tripping on downed timber.

Urbanization has brought about an increase in human-bear interactions (Baruch-Mordo et al. 2008), particularly in the western United States. Availability of anthropogenic food sources in towns occupying mountainous regions has increased conflicts between bears and humans, with subsequent effects to local bear populations (Beckmann and Lackey 2008). Some of these conflicts were originally believed to be the result of **social learning** (i.e., sows teaching their cubs to raid garbage), but genetic evidence suggests, "the acquisition of food conditioning behavior was not solely a function of social learning or inheritance" (Breck et al. 2008:428).

Black bears can cause significant damage to trees, especially in second-growth forests (Noble and Meslow 1998, Partridge et al. 2001, Nolte and Dykzeul 2002). Damage can be recognized by the large, vertical incisor marks and claw marks on the sapwood and ragged strips of hanging bark, or branches broken to feed on fruit (Hygnstrom 1994). Most bark damage occurs during May to July. Damage to field crops also can be substantial, with corn and oats being preferred crops (Hygnstrom 1994). **Damage management techniques** include supplemental feeding, aversive conditioning, fencing, frightening devices, hazing, repellents, traps (foothold and live traps), foot snares, and hunting with dogs.

Coyotes, Wolves, and Dogs

These canid predators prey on animals ranging in size from big game and livestock to native birds, poultry, and rodents (Andelt and Gipson 1979, Carbyn 1987, Voigt and Berg 1987). **Coyotes** are the most common and most serious predator of livestock in the western United States (Agricultural Statistics Board 2005) and are becoming more of a problem in the eastern United States. Coyotes normally kill livestock with bites to the neck and throat, but may pull the animal down by attacking the side and hindquarters (O'Gara 1978a,

Wade and Bowns 1982, Green et al. 1994, Acorn and Dorrance 1998). The rumen and intestines are not eaten, but often removed and dragged away from the carcass. When canids kill small lambs, their upper canine teeth can penetrate the top of the neck or the skull (Wade and Bowns 1982). Calf predation by coyotes is most common when calves are young. Calves attacked, but not killed, exhibit wounds to the flank, hindquarter, or front shoulder (Wade and Bowns 1982). Deer that are killed are completely dismembered and eaten (VerCauteren et al. 2005a). With increased urbanization, complaints of pets being killed by coyotes have increased and attacks on humans (mainly children) are an increasing concern in urban areas. Agricultural producers using drip irrigation systems report that coyotes chew holes in plastic pipe and disrupt irrigation (Werner et al. 1997). Fruit crops, particularly watermelons (*Citrullus lanatus*), also can be consumed or damaged by coyotes (Green et al. 1994).

Wolves prey mainly on larger ungulates such as deer, caribou, moose, elk, and cattle. Cattle, especially calves, are most vulnerable to wolf predation (Paul and Gipson 1994, Acorn and Dorrance 1998), as are domestic sheep (Gula 2008). Although predation on livestock is usually rare (Fritts et al. 1992, Oakleaf et al. 2003), wolf predation on cattle and sheep has been increasing in the Northern Rocky Mountain states as wolf recovery progresses (Bangs et al. 2006). Wolves usually kill ungulates by attacking the hindquarters or by seizing the flanks (Paul and Gipson 1994). Slash marks made by the canine teeth may be found on the rear legs and flanks (VerCauteren et al. 2005a). When the victim is badly wounded and collapses, wolves will often disembowel the animal (Paul and Gipson 1994). Wolves usually eat the viscera and hindquarters first. Most of the carcass is consumed and large bones may be chewed or cracked open (Acorn and Dorrance 1998). Wolves may carry parts of the carcass to dens or rendezvous sites for the pups to consume.

Domestic dogs can be a serious problem to livestock, especially to sheep pastured near cities and suburbs (Green and Gipson 1994). Dogs may be indiscriminate as to how and where they attack, but often attack the hindquarters, flanks, and head, and rarely kill as effectively as coyotes (Green and Gipson 1994, VerCauteren et al. 2005a). O'Gara (1978a) considered dogs to be "sloppy" killers, often slashing and tearing victims and leaving many cripples (Acorn and Dorrance 1998). If dogs eat sheep or big game, they normally eat the hams and often vomit near the site (O'Gara 1978a). Normally little flesh is consumed (Green and Gipson 1994, Acorn and Dorrance 1998). Dogs generally wound the animal in the neck and front shoulders; the ears often are badly torn (VerCauteren et al. 2005a). Attacking dogs often severely mutilate the prey (Acorn and Dorrance 1998); skinning the animal will often reveal 80% of the body bruised by bites that did not penetrate the skin (O'Gara 1978a).

Coyote and dog tracks are similar, but distinguishable. The larger size of wolf tracks often separates them from

coyotes and dogs. Coyote tracks are more oval in shape and compact than dogs (Green et al. 1994, Acorn and Dorrance 1998). Dog tracks are round with the toes spread apart and toenail marks usually are visible on all toes. Coyote tracks tend to follow a straight line more closely than dogs (Murie 1954, Green et al. 1994). **Damage management techniques** include livestock husbandry practices, livestock protection collars, guard animals (dogs, llamas [*Lama glama*], and donkeys [*Equus asinus*]), electronic training collar, fencing, frightening devices, reproductive interference, M-44s, aerial hunting, calling and shooting, denning, traps (foothold), and snares.

Mountain Lions, Bobcats, and Lynx

Felids that cause damage are primarily mountain lions, bobcats, and lynx (*L. canadensis*). **Mountain lions** are primarily carnivorous and prey on native ungulates (mainly deer and elk), and livestock (particularly horses, sheep, goats, and cattle; Lindzey 1987). They also will eat rodents and other small mammals when available (VerCauteren et al. 2005a). Livestock depredations are often random and unpredictable; it is common for several animals to be killed in a short period of time (Knight 1994a).

Sheep, goats, calves, and deer are typically killed by mountain lions with bites to the top of the neck or head (Knight 1994a, Acorn and Dorrance 1998). Lions also may sever the vertebral column and break the neck of their prey. Mountain lions kill in a similar manner to bobcats, but the tooth punctures will be larger (0.63–0.79 cm) and more round than bobcat punctures (O'Gara 1978a). Strips of skin also will be present at the kill site from the lacerations caused by the lion's claws. Mountain lions usually feed first upon the shoulders of their prey (O'Gara 1978a). The stomach generally is untouched (Acorn and Dorrance 1998). The large leg bones of prey may be crushed and ribs may be broken (VerCauteren et al. 2005a). Often a lion will cover its kill with soil, leaves, grass, and debris (Knight 1994a) and may return to feed for 3–4 nights. They normally uncover the kill at each feeding and move it 10–25 m before covering the carcass again. After the last feeding, the remains may be left uncovered (Shaw 1983).

Mountain lion tracks may be difficult to observe except in snow or sandy or wet soil (Murie 1954). Adult lion tracks are approximately 10 cm across and have a distinguishable 3-lobed heel pad (Knight 1994a). Mountain lions have retractable claws; therefore, no claw marks will be evident. Large dog tracks could be confused with lion tracks. However, dog tracks normally show distinctive claw marks, are less round than mountain lion tracks, and have different heel-pad marks (VerCauteren et al. 2005a).

Bobcats are opportunistic predators, feeding mainly on rabbits, rodents, and birds (Rolley 1987). They will occasionally kill and consume poultry, goats, small dogs, house cats, and rarely, calves (Virchow and Hogeland 1994) and sheep (Neale et al. 1998). Bobcats usually kill their prey by biting

the back of the neck or base of the skull (O'Gara 1978a). Bobcats often may be carried a short distance by an adult deer before completing the kill. Victims usually die of suffocation and shock, or from dislocated neck vertebrae. Hair and strips of hide may be found at the site where the cat first attacked. **Scratches** are usually evident on the shoulders, back, or sides of the prey (Virchow and Hogeland 1994). Bobcats often attack and kill lambs by holding the victim with their claws while biting the neck or head. Skulls of the victim may be fractured, but not crushed like those bitten by coyotes (O'Gara 1978a). The hindquarters of deer or sheep usually are eaten first by bobcats, although the shoulder, neck, or flank also may be consumed first. The rumen is often untouched. Carcasses are usually covered before being left and may be buried under leaves, snow, or soil, or the remains may be carried and cached under shrubs (O'Gara 1978a, Virchow and Hogeland 1994). Bobcats reach out 30–35 cm when covering their kill, whereas mountain lions reach out to 90 cm (Young 1958). Poultry usually are killed by biting the head and neck (Young 1958); the heads usually are eaten. Tooth punctures from a bobcat are similar to those of a coyote, but tend to slash more than those of canids (O'Gara 1978a). The distance between the canine teeth marks also will help distinguish a mountain lion kill from a bobcat kill: 3.8 cm versus 1.9–2.5 cm, respectively (Wade and Bowns 1982). *Lynx* may kill livestock (Odden et al. 2008), but mainly specialize on snowshoe hares (*Lepus americanus*; Quinn and Parker 1987). Bobcat and lynx feces are similar in size and shape (Murie 1954). In areas inhabited by both species, careful examination of the tracks will help identify the species responsible for a depredation event. The lynx has larger feet with much more hair, and the toes tend to spread more than those of bobcats (Murie 1954). Small **Neotropical felids** in the United States, such as the ocelot (*Leopardus pardalis*), margay (*L. wiedii*), and jaguarundi (*Herpailurus yagouaroundi*), pose little threat to livestock, but may occasionally kill a chicken. They mainly consume native birds, small mammals, and reptiles (Tewes and Schmidly 1987). **Damage management techniques** include fencing, frightening devices, traps (foothold), snares, and hunting (by calling and shooting and with dogs).

Foxes

Gray (*Urocyon cinereoargenteus*) and **red foxes** feed primarily on rabbits, hares, small rodents, poultry, birds, fruit, and insects (Voigt 1987). Although poultry is the most commonly killed domestic prey, red foxes (and to a lesser extent gray foxes) may prey on livestock, mainly lambs and kids (Phillips and Schmidt 1994). Predation of poultry by **swift and kit foxes** is almost nonexistent (O'Farrell 1987, Scott-Brown et al. 1987). **Arctic foxes** (*V. lagopus*) may prey on livestock (Garrott and Eberhardt 1987). Foxes usually attack the throat of lambs and kids, but kill some prey by multiple bites to the neck and back (Wade and Bowns 1982, VerCauteren et al.

2005a). Foxes do not have the body or jaw power of larger canids; thus, they are unable to seize and immobilize large prey and multiple bites may be evident (Wade and Bowns 1982). Foxes generally eat the viscera first and may begin feeding through the ribs. Foxes killing fowl usually leave behind only a few drops of blood and feathers and carry the prey from the kill location (Phillips and Schmidt 1994). Eggs usually are opened enough to allow the contents to be licked out and are often left beside the nest (VerCauteren et al. 2005a).

When attempting to identify the predator of a depredated animal, note the canine teeth are smaller and the spacing is narrower in foxes compared to coyotes (Wade and Bowns 1982). Red fox tracks may resemble coyote tracks, but fox tracks are generally smaller than coyote tracks and have a shorter stride (Murie 1954). Gray fox tracks are slightly smaller than those of red foxes. **Damage management techniques** include guard dogs, fencing, frightening devices, M-44s, aerial hunting, traps (foothold), snares, calling and shooting, and hunting dogs.

Opossums

Opossums (*Didelphis marsupialis*) are primarily insectivorous and omnivorous and prefer fish, crustaceans, insects, mushrooms, fruits, vegetables, eggs, and carrion (Seidensticker et al. 1987). Opossums will occasionally raid poultry houses and generally kill one chicken at a time, often mauling the victim. Eggs will be mashed and messy; the shells often are chewed into small pieces and left in the nest. Young poultry or game birds are consumed entirely. Opossums in urban areas may be a nuisance where they get into garbage cans, compost piles, bird feeders, and pet food (Jackson 1994a). **Damage management techniques** include fencing, traps (foothold and live traps), shooting, and hunting dogs.

Raccoons

Raccoons are omnivorous predators, eating mice, birds, snakes, frogs, insects, crawfish, grass, berries, acorns, corn, melons, turtle eggs, and various grain crops (Sanderson 1987). Raccoons are notorious for raiding fields of sweet corn and tearing ears off the plants. In watermelon fields, raccoons will dig into the melon and scoop out the contents with their front paws (Boggess 1994). In urban areas, raccoons readily raid garbage cans and dumps. They cause damage to buildings when gaining access to attics and chimneys. Agricultural fields and gardens near wooded areas may experience damage from raccoons. Raccoons may prey on eggs and young of ground- and cavity-nesting birds, or raid artificial nesting structures (Boggess 1994). Predation by raccoons on nests of sea turtles (Ratnaswamy et al. 1997), ancient murrelets (*Synthliboramphus antiquus*; Hartman et al. 1997), and other threatened and endangered species is a growing concern for conservation efforts.

Raccoons rarely kill small lambs. When they do, they usually grab their prey with their paws and bite the neck

(O'Gara 1978a). Similar to the bites of a fox, bites from a raccoon attack usually encircle the whole neck (O'Gara 1978a). Skinning the carcass will reveal bruises where the prey was grabbed, but not deep scratches as with bobcats. Raccoons often feed on a carcass at the loins or by making a small hole in the side of the carcass and pulling the viscera from the body cavity to consume it (O'Gara 1978a). Raccoons occasionally raid poultry houses and may kill many birds in a night. The heads of adult birds are usually bitten off and left, the breast and crop may be torn and chewed, and the entrails may be consumed (Boggess 1994). Young birds in pens or cages may be killed or injured when the raccoon grabs a bird through the wire mesh and tries to pull it from the cage. Eggs may be removed and eaten away from the nest, or consumed on the spot with only shell fragments remaining.

Raccoons leave a distinctive 5-toed track resembling a small human handprint (Boggess 1994). Tracks usually are paired, and the left hind foot is placed beside the right forefoot. Raccoon and opossum tracks can be difficult to distinguish in soft sand where toe prints are not distinctive. **Damage management techniques** include fencing, traps (foothold and live traps), shooting, and hunting dogs.

Skunks

Skunks are opportunistic omnivorous predators consuming insects (particularly grasshoppers, beetles, and crickets), bird eggs, mice, and occasionally rats and cottontail rabbits (Rosatte 1987, Knight 1994b). Skunks become a nuisance when they dig small (7–10-cm), cone-shaped holes, or turn over patches of earth in lawns, gardens, and golf courses in search of insect grubs (VerCauteren et al. 2005a). They may burrow under porches and buildings. Their odor is a common complaint when they take up residence under human dwellings. Skunks may damage beehives when attempting to eat the bees.

Skunks are major predators of waterfowl nests. Non-lethal techniques to reduce skunk predation on waterfowl nests have had limited success (Greenwood and Sovada 1996, Greenwood et al. 1998). Skunks occasionally kill domestic poultry and eat eggs, but usually will not climb fences to raid poultry houses (Knight 1994b). When skunks kill poultry, they generally kill only 1–2 birds, and often maul them. Eggs usually are opened at one end with the edges crushed inward as the skunk punches its nose into the hole to lick out the contents (Knight 1994b). When in a more advanced stage of incubation, eggs are likely to be chewed in small pieces. Eggs may be removed from the nest, but are rarely moved far (VerCauteren et al. 2005a).

Inhabited dens can be recognized by fresh droppings containing undigested insect parts near the mound or hole (VerCauteren et al. 2005a). Dens usually have a characteristic skunk odor, although the odor may not be strong. Tracks are relatively distinctive with both front and rear feet having

5 toes, with claw marks often visible (Knight 1994b). The heel of the forefeet may not be visible and in some cases, the fifth toe may not be obvious (Knight 1994b). **Damage management techniques** for skunks include fencing, repellents and fumigants, traps (foothold and live traps), and shooting.

Weasels and Mink

Weasels (*Mustela erminea*, *M. frenata*, and *M. nivalis*) feed mainly on insects and small rodents, and occasionally prey on birds, fish, amphibians, reptiles, nests of ground-nesting birds, and berries (Fagerstone 1987). Mink are generalists and feed mainly on small rodents, muskrats, and lagomorphs. Mink also will prey upon fish, birds, and invertebrates (Eagle and Whitman 1987). Weasels and mink have a similar killing pattern in which they bite the prey item through the skull and upper neck. When feeding on muskrats, mink will often make an opening at the back or side of the neck. As the mink consumes the flesh, ribs, and pieces of the adjacent hide, the head and hindquarters are pulled through the same hole and the animal is skinned; weasels demonstrate a similar feeding pattern when consuming small rodents.

Weasels and mink will raid poultry houses at night and kill or injure fowl (Henderson 1994b). They often kill many birds by biting them in the head and often eat only the heads of the victims, but will consume the body as well. Rat predation usually differs from weasel predation in that portions of the chicken are eaten and carcasses are dragged into holes or concealed places (Henderson 1994b). Waterfowl eggs destroyed by weasels tend to be broken at the ends, with openings 15–20 mm in diameter (Teer 1964). Close examination of shell fragments will often disclose finely chewed edges and tiny tooth marks left by a weasel (Rearden 1951).

Weasels den in burrows in the ground, under rocks or brush piles, in barns, or in piles of stored hay (VerCauteren et al. 2005a). The den itself is an enlarged chamber (3.5–5.0 cm) lined with dry grass and the fur of previous kills (Fagerstone 1987). **Mink** may use cavities in roots of trees, rocks, brush piles, logjams, and beaver lodges (Eagle and Whitman 1987). Mink also will use abandoned burrows of other animals as den sites, especially those of muskrats. **Damage management techniques** include fencing and traps (Conibear, foothold, and live traps).

Feral Cats

Feral cats are house cats living in the wild, although even house cats can cause damage by killing native small mammals and songbirds (Soulé et al. 1988, Crooks and Soulé 1999). Feral cats are opportunistic predators that prey on ducks, pheasants, rabbits, quail, rodents, insects, reptiles, amphibians, and fish (Fitzwater 1994). Similar to feral dogs, feral cats are often described as "sloppy" killers, with parts of their prey strewn about when feeding. Cats generally consume the meaty portions of large birds, leaving loose skin with

feathers attached (VerCauteren et al. 2005a). Small birds generally are consumed and only the wings and scattered feathers remain. Cats usually leave tooth marks on every exposed bone of their prey. Nesting birds are vulnerable to cat predation and cats can exact a heavy toll on bird populations (Churcher and Lawton 1987, Jurek 1994, Coleman et al. 1997). Unlike domestic house cats, feral cats often are extremely wary of humans. **Damage management techniques** include fencing, frightening devices (dogs), traps (foothold and live traps), snares, and shooting.

Management Techniques

Protecting livestock and poultry from predators is a complex endeavor, with each case requiring an assessment of the legal, social, economic, biological, and technical aspects, with no one technique solving the problem in all circumstances (Knowlton et al. 1999, Bangs et al. 2006). Successful resolution of conflicts with predators involves an analysis of the efficacy, selectivity, and efficiency of various management scenarios (Knowlton et al. 1999, Gese et al. 2005), with an integration of opportunities to empower the local public to protect their private property (Bangs et al. 2006). **Control techniques** may be considered either **corrective** (after a depredation event) or **preventive** (before the event). Selectivity of the technique is important when attempting to solve the depredation problem (Mitchell et al. 2004). Results from general population reduction are mixed. Sometimes reducing the size of the predator population reduces depredations (e.g., Herfindal et al. 2005), while other times it has no effect on solving the depredation problem (e.g., Conner et al. 1998). Certain techniques (e.g., livestock protection collars, calling and shooting) that **selectively** remove the offending individual (Sacks et al. 1999a, b; Blejwas et al. 2002) are **nonselective** techniques (e.g., traps or snares) that predators learn to avoid (Sacks et al. 1999a), or that may create more wary animals (Mettler and Shivik 2007). Identifying the "problem" animal can be difficult (Linnell et al. 1999). Methods that are more benign in their effects on other species are preferred to those creating greater perturbations (Knowlton et al. 1999). Often, providing livestock producers a variety of tools to manage depredation may improve the likelihood of acceptance of predators (Bangs et al. 2006). Increased predation on livestock may be exasperated when native prey species decline in abundance, thereby reducing their **buffering effects** (Knowlton et al. 1999, Stoddart et al. 2001, Sacks and Neale 2007).

A diverse array of techniques (nonlethal and lethal) has been used to prevent or deter depredations on livestock and poultry (Green et al. 1994, Knowlton et al. 1999, Gese et al. 2005). Regrettably, many of these techniques do not often carry over to protecting wildlife resources. However, Seidler (2009) recently documented that sterilization of coyotes increased pronghorn fawn survival. Some techniques developed for protection of domestic commodities (e.g., fencing, lethal removal) may reduce depredations on natural re-

sources (Ratnaswamy et al. 1997, Garrettson and Rohwer 2001), but are generally limited to small-scale applications. Most nonlethal procedures are within the operational purview of the agricultural producer. Livestock producers spent close to \$200 million on **nonlethal techniques** in 2005, with **guard animals, exclusion fencing, and frequent checking of stock** the most common methods employed (Agricultural Statistics Board 2006). Although there are reports of success with some methods, failures are common; few such methods have been subjected to critical evaluation or testing, and none have proven a panacea (Knowlton et al. 1999).

Livestock Husbandry Practices

Various livestock management practices have been suggested as a means of reducing depredation losses (Robel et al. 1981, Wagner 1988, Acorn and Dorrance 1998). Some of the most common **practices include** (1) confining or concentrating flocks during periods of vulnerability (e.g., at night or during lambing), (2) using herders, (3) shed-lambing, (4) removing livestock carrion from pastures, (5) synchronizing birthing, and (6) keeping young animals in areas with little cover and in proximity to human activity (Knowlton et al. 1999). These procedures generally require additional resources and effort, and frequently only delay onset of predation, or may have undesirable side effects (Knowlton et al. 1999). For these methods to be effective, producers must develop strategies for their own situations. Producers also must realize that economic advantages of modifying their husbandry practices may be difficult to demonstrate (Knowlton et al. 1999), but can assist in herd management and production. Surveys indicate that producers used fencing (52%), night penning (33%), and guard dogs (32%) in their sheep management operations (Agricultural Statistics Board 2005).

Guard Dogs

Use of **guard dogs** to deter coyotes from livestock has been used traditionally by many sheep producers, particularly in fenced pastures (Acorn and Dorrance 1998). In several western states, about 32% of producers surveyed used guard dogs to protect their flocks (Agricultural Statistics Board 2000). In Colorado, Andelt (1992) reported that sheep producers estimated their guard dogs saved an average of \$3,216 worth of sheep annually and reduced their need for other control techniques. **Dog breeds** most commonly used as livestock guardians include Great Pyrenees, Komondor, Akbash, Anatolian, and Maremma (Fig. 34.18). Although there does not appear to be one breed that is most effective, livestock producers rated Akbash as more effective at deterring predation because it was more aggressive, active, intelligent, and faster (Andelt 1999). The Great Pyrenees was the most common guard dog breed in Alberta, Canada (Acorn and Dorrance 1998). Studies investigating efficacy of guard dogs have shown the dogs to be effective in some situations and ineffective in others (Linhart et al. 1979, Coppinger et al. 1983, Green et al. 1984, Green and Woodruff 1987, Conner



Fig. 34.18. Various dog breeds can be used to defend domestic livestock from predators. Photo by U.S. Fish and Wildlife Service.

1995, Andelt and Hopper 2000). This disparity may be due to the inherent difficulty guard dogs have in effectively protecting large flocks that are dispersed over rough terrain and/or in areas where thick cover conceals approaching predators. Training and close supervision of the dogs are important for success with this technique (Acorn and Dorrance 1998). Some poorly trained or minimally supervised guard dogs have killed sheep and lambs, harassed or killed wildlife, and threatened people that intrude upon their territory. However, not all guard dog failures or undesired behaviors stem from poor training or supervision. There is considerable behavioral diversity within a litter of guard dog pups; some turn into valuable and effective guard animals, while others do not, despite similar training and effort. Use of guard dogs precludes use of other control devices (e.g., traps, snares, M-44s) and techniques (e.g., calling and shooting; Knowlton et al. 1999). Dogs can be killed or injured by poisons, snares, and traps used for predator control (Acorn and Dorrance 1998).

Guard Llamas

Use of **llamas** for protecting livestock from predators takes advantage of the llama's evolution with predators and their aggressiveness toward predators (Fig. 34.19). Use of llamas as guard animals is growing in popularity, with about 22% of western producers surveyed using them (Agricultural Statistics Board 2000). Studies have found use of llamas to be a practical and effective technique to deter predators, mainly coyotes and dogs, from depredating livestock (Franklin and Powell 1994, Meadows and Knowlton 2000). Llamas can be kept in fenced pastures with sheep or goats, do not require any special feeding program, are relatively easy to handle, and live longer than guard dogs (Knowlton et al. 1999). Although guard animals may not deter coyotes from inhabiting the immediate area near livestock, they may change predators' behavior and activity patterns when in those areas (Knowlton et al. 1999). Traits that may be useful in selecting a guard llama include dominance, alertness, and body weight (Cavalcanti and Knowlton 1998).

Guard Donkeys

Donkeys also have been used as livestock guardians (Green 1989, Acorn and Dorrance 1998), with about 6% of produc-

ers in the western United States using donkeys as a management tool (Agricultural Statistics Board 2000). The protective behavior of donkeys apparently stems from their dislike of dogs. A donkey will bray, bare its teeth, chase, and try to kick and bite coyotes and dogs (Acorn and Dorrance 1998). Recommendations on using guard donkeys include using only a jenny (female) or gelded jack (male; intact jacks are too aggressive toward livestock), and placing one donkey per flock or group while keeping other donkeys or horses away to prevent the guard donkey from bonding with any animal except those to be protected. Furthermore, donkeys should be introduced to the livestock about 4–6 weeks prior to the onset of anticipated predation events to properly bond with the group (Acorn and Dorrance 1998). Donkeys are most effective in small, fenced pastures.

Supplemental Feeding

Supplemental feeding, to divert a predator from a vulnerable commodity, has received some attention. Many predators will readily consume food provisioned by humans. Greenwood et al. (1998) found that although skunks and other predators responded to supplemental feeding, depredations on waterfowl nests remained unchanged. They concluded that food provisioning had limited value for managing depredations on waterfowl nests in the Prairie Pothole region of North America because the predator community was large and complex. In the Pacific Northwest, black bears damage coniferous trees by feeding on sapwood during spring (Noble and Meslow 1998, Partridge et al. 2001). Collins (1999) reported that damage to trees by black bears was highest in areas where bears did not receive supplemental feeding (i.e., pellet feeders). Supplemental feeding of bears reduced damage to the trees (Ziegler 2004), with apparently no long-lasting effect on bear condition or productivity (Partridge et al. 2001). One also must consider how the animal community may respond to supplemental feeding. Godbois et al. (2004) observed that supplemental feeding of northern bobwhite (*Colinus virginianus*) resulted in a spatial



Fig. 34.19. Llamas are often used to defend domestic sheep from predators. Photo by U.S. Fish and Wildlife Service.

response of bobcats; radiocollared bobcats were found 10 times closer to the supplemental food than expected.

Fencing and Barriers

Livestock, poultry, crops, and waterfowl and sea turtle nests may be protected from predators with a properly constructed and located barrier. However, West et al. (2007) documented that red foxes routinely penetrated fences designed to protect waterfowl nests, and they questioned many fence designs that had been previously recommended. About 52% of livestock producers surveyed stated that they used fencing to reduce predator losses to sheep and lambs (Agricultural Statistics Board 2005). **Barriers** may take the form of flagging or fladry (Musiani et al. 2003, Shivik et al. 2003), an enclosure, electric fence, nest screen, or even a moat (e.g., deCalesta and Cropsey 1978, Linhart et al. 1982, Shelton 1984, Nass and Theade 1988, Melvin et al. 1992, Lokemoen and Woodward 1993, Ratnaswamy et al. 1997). **Standard fencing** will not keep most predators from entering gardens or poultry ranges because they learn to jump over or dig under such fences. Many large predators may be deterred or excluded by adding an **electrified** single-wire strand charged by a commercial fence charger along a wire mesh fence. The electrified wire should be placed 20 cm outside of the main fence line and 20 cm above the ground (VerCauteren et al. 2005a). A fence 1.5 m high with 9–12 alternating ground and charged wires spaced 10–15 cm apart is an effective barrier against coyotes (Gates et al. 1978, Acorn and Dorrance 1998). A high-tensile **woven-wire fence** that is more versatile, longer lasting, and can be tightened more than conventional wire mesh, also can be used (Acorn and Dorrance 1998).

Skunks may be deterred from entering a poultry area with a 0.9-m-high wire mesh fence extending 0.6 m above-ground and 0.3 m below the surface; a 15-cm length of the portion belowground should be bent outward at right angles and buried 15 cm deep (VerCauteren et al. 2005a). **Mink and weasels** may be excluded from barns or coops by covering all openings larger than 2.5 cm with metal or hardware cloth. **Asiatic black bears** (*U. thibetanus*) in Japan were deterred from entering crop fields and apiaries with an electric fence (Huygens and Hayashi 1999). Installation costs usually preclude use of fences for protecting livestock in large pastures or under range conditions. For wildlife resources, fencing may be best suited to protecting waterfowl nests or high-value commodities in small areas (e.g., sea turtle nests; Ratnaswamy et al. 1997). If electric fencing is used, the behavior of the wildlife resource being protected also should be considered (Trottier et al. 1994) and modifications to the design may assist in protection efforts without deleterious effects on the species being protected (Pietz and Krapu 1994).

Frightening Devices

Lights, distress calls, loud noises, scarecrows, plastic streamers, propane cannons, aluminum pie pans, and lanterns have

been used to **frighten predators** (Acorn and Dorrance 1998). Most testing has focused on devices that periodically emit bursts of light or sound to deter coyotes from sheep in fenced pastures and open-range situations (Linhart 1984; Linhart et al. 1984, 1992), but the benefits are short-lived (Bomford and O'Brien 1990, Koehler et al. 1990, Darrow and Shivik 2009). All of these devices can provide temporary relief from damage or in deterring predators, but habituation and learning by predators is common (Acorn and Dorrance 1998, Shivik 2006). Changing the location of devices, the pattern of the disruptive-stimuli (Shivik 2006), or combining several techniques can prolong the frightening effect (Linhart et al. 1992). Linhart (1984) reported that a combination of **warbling-type sirens and strobe lights** reduced coyote predation on lambs by 44%. These battery-operated devices were activated in the evening by a photocell set on a schedule of 10-second bursts at 7–13-minute intervals. Pfeifer and Goos (1982) found use of **propane exploders** delayed or temporarily prevented lamb losses to coyotes. Similarly, VerCauteren et al. (2003c) reported no kills during the lambing period when flocks were bedded near predator-activated frightening devices. Darrow and Shivik (2009) suggested that **light** may be the most important component of a frightening device. A new device, the **Nuisance Bear Controller**, proved effective at deterring black bears from raiding bird feeders, was relatively inexpensive, portable, and could be used to deter bears from concentrated food sources (Breck et al. 2006).

A recent development used to deter wolf predation is the **Radio Activated Guard (RAG) box** (Shivik and Martin 2001, Breck et al. 2002) and the **Movement Activated Guard (MAG) device** (Shivik et al. 2003). The RAG is activated only when a radiocollared wolf is in the vicinity, preventing habituation of the animal to the lights and siren. The RAG has application only in areas with radioed animals, but can deter endangered predators from causing problems to livestock producers (Breck et al. 2002). The MAG device is activated by a passive infrared detector and sets off lights and sound to scare away predators from the area (Shivik et al. 2003). Use of frightening devices is not widespread, with only 6% of producers using frightening devices (Agricultural Statistics Board 2000). The use of sirens and strobe lights at night near people is generally not acceptable (Knowlton et al. 1999).

Repellents and Aversive Conditioning

Presently, no commercial repellents deter predation (Knowlton et al. 1999). A variety of **gustatory, olfactory, and irritating** compounds have been tested, with a few (e.g., thia-benzazole, pulegone, cinnamaldehyde, allyl sulfide) reducing food consumption among predators (Hoover and Conover 1998, 2000; Ternent and Garshelis 1999). Although quinine hydrochloride and capsaicin may discourage coyotes from chewing on irrigation hoses (Werner et al. 1997), there is little information demonstrating that these repellents deter predation (Lehner 1987, Burns and Mason 1997). Polson (1983)

used thiabendazole to condition black bears to avoid beehives. Ternent and Garshelis (1999) reported that black bears could be discouraged from consuming meals-ready-to-eat (MREs) on a military reservation by treating the MREs with thiabendazole. Skunks may be repelled from areas with ammonia-soaked cloths or mothballs (Knight 1994b).

Conditioned taste aversion, using lithium chloride, to reduce coyote predation on sheep had received much attention >20 years ago. Study results were mixed, with some reporting success (Gustavson et al. 1974, 1982; Ellins and Martin 1981; Forthman-Quick et al. 1985a, b), while others were either unable to replicate those findings or found lithium chloride to be ineffective in the field (Conover et al. 1977; Burns 1980, 1983; Bourne and Dorrance 1982; Burns and Connolly 1985). Although lithium chloride reduces prey consumption, it does not deter the act of predation. Ten years after field trials using lithium chloride (Gustavson et al. 1982, Jelinski et al. 1983), a survey of the same sheep producers revealed only one producer still used it (Conover and Kessler 1994). Evidence suggests that conditioned taste aversions are either ineffective or unreliable for deterring predation (Knowlton et al. 1999), but may limit food consumption (Polson 1983, Ternent and Garshelis 1999). Predation on sea turtle nests by raccoons was unaffected using conditioned taste aversion (Ratnaswamy et al. 1997).

Aversive conditioning may be effective in "teaching" brown bears to fear and avoid humans (Jonkel 1994). For valuable endangered species, the expense may be necessary, considering the alternative for problem bears is usually destruction of the animal (Jonkel 1994). In many national parks, lethal techniques are considered the last resort when dealing with problem carnivores. Hazing of these animals is implemented in an attempt to discourage these animals from returning to a campground, landfill, or residential area. **Hazing** often involves park personnel yelling, firing cracker shells or rubber slugs, or chasing the animals with trained dogs, thereby pursuing the animal until it has left the area (Yosemite National Park 2003). Breck et al. (2007) reported on an automated system developed to alert park personnel whenever a radiocollared bear entered a particular area in Yosemite National Park, allowing personnel to respond promptly before the situation progressed. Leigh and Chamberlain (2008) reported that of 11 black bears exposed to aversive conditioning involving rubber buckshot and dogs, 10 (91%) returned to nuisance behavior within 5 months, and concluded these techniques had limited short-term effectiveness.

Electronic Training Collar

A device receiving attention as a nonlethal method to deter coyote and wolf predation on livestock is an electronic training (shock) collar used for training domestic dogs (Andelt et al. 1999, Shivik and Martin 2001, Shivik et al. 2003, Schultz et al. 2005). Using captive coyotes, Andelt et al. (1999) reported the training sequence with the electronic collar stopped all attempted attacks on lambs, decreased the prob-

ability of an attempted attack, eliminated successive chases, and even caused avoidance of lambs. Hawley et al. (2009) tested the use of electronic collars on wolves and found wolves did shift farther away from bait stations after being shocked, but conditioning was not clearly demonstrated once shocking ceased. All investigators caution that application may be limited under field conditions because the predator must be captured and the training collar attached, but do suggest that changing the behavior of the predator during the attack phase of a predatory sequence holds promise as a nonlethal technique (Andelt et al. 1999, Shivik and Martin 2001).

Reproductive Interference

An interest in influencing the reproductive rate of canids with **chemical sterilants** dating to the 1960s assumed that reduced reproduction would reduce population levels and that fewer predators would result in fewer depredations (Balser 1964, Knowlton et al. 1999). Trials with diethylstilbesterol indicated that reproduction among coyotes could be curtailed (Balser 1964, Linhart et al. 1968), but timing was critical and the approach was impractical without an effective delivery system (Knowlton et al. 1999). Currently there is renewed interest in reproductive inhibition using immunocontraceptive agents (DeLiberto et al. 1998, Levy et al. 2004, Fagerstone et al. 2008), both as a means of reducing predator populations (Ramsey 2007) or changing predatory behavior (Till and Knowlton 1983, Bromley and Gese 2001a). Conner et al. (2008), using a spatially explicit, individual-based model, indicated that sterilization of coyotes appeared to be the management strategy that had the largest and most lasting impact on coyote population dynamics. **Surgical sterilization** (tubal ligation and vasectomy) of coyotes was effective in reducing predation rates on domestic lambs by changing predatory behavior and did not affect social behavior and territory maintenance (Bromley and Gese 2001a, b). **Vasectomy** of male wolves has been proposed as a method of population control (Haight and Mech 1997). However, currently there are no substances available for fertility control in predators that are species-specific; specificity might be achieved with appropriately designed delivery systems. In Australia, immunocontraception was investigated for fertility control and population reduction of nonnative red foxes (Strive et al. 2007).

Relocation of Problem Animals

Management programs using **relocation** of problem animals has had limited success for grizzly bears (Brannon 1987), but less so with wolves killing livestock (Bangs et al. 1995, Cluff and Murray 1995). Wolves that learn to kill livestock often return to the capture site, or begin killing livestock in the new area and have to be removed from the population (Bangs et al. 1995). Although relocation efforts are expensive, they are considered worthwhile and necessary when dealing with endangered predatory species.

Financial Incentives

Resistance by the livestock community to recovery of wolves in the Northern Rocky Mountains was tempered by **compensation** for livestock losses. Compensation programs for livestock deaths from some predatory species exist in the United States and Canada (Fritts 1982, Gunson 1983, Fritts et al. 1992). Problems identified with compensation programs are that producers believe they do not receive fair market value, that compensation is only for verified losses (does not include missing animals), and that payment for losses does not encourage producers to correct poor management practices or attempt nonlethal techniques (Fritts et al. 1992). Bulte and Rondeau (2005) cautioned that compensation programs could actually cause adverse effects to wildlife by increasing agricultural expansion and habitat conversion, decreasing efforts to prevent damage, and intensifying agricultural production. A careful assessment of local ecological and economic conditions should be performed before implementing a compensation program, and incentives may best be realized if tied to conservation outcomes (Bulte and Rondeau 2005). A recent incentive has been the production of "predator friendly" products in which consumers pay more for goods (e.g., wool, meat) that come from ranches that do not kill predators.

Livestock Protection Collar

The **livestock protection collar** (LPC) is a collar with an attached rubber pouch or bladder filled with Compound 1080. The device is placed around the neck of lambs and kid goats (Acorn and Dorrance 1998). **Compound 1080** is an acute toxicant formerly used as a predicide and rodenticide. Most predicide uses were banned in 1972 because of non-target hazards, and rodenticide uses were banned in 1990 (Fagerstone and Schafer 1998). The LPC is designed to kill coyotes when they puncture the bladders during an attack on a lamb or kid. The major advantage of LPCs is that they selectively remove the problem animal and frequently kill individual predators that have evaded other control techniques (Connolly 1980, Connolly and Burns 1990, Blejwas et al. 2002). The LPC comes in 2 sizes (large and small), with the larger LPC working effectively on larger lambs (Burns et al. 1996). The major disadvantages of LPCs are initial purchase costs and labor required for application and maintenance (collars must be adjusted as animals grow), incidental puncturing of the collar (by thorns, wire, or other snags), anticipating which lambs or kids are most likely to be attacked, and keeping accurate records of the amount of predicide used in each LPC (Wade 1985, Acorn and Dorrance 1998, Knowlton et al. 1999).

M-44

The **M-44** is a mechanical device that ejects sodium cyanide into the mouth of an animal after it pulls on the device (Connolly 1988, Acorn and Dorrance 1998). The unit consists of

a case holder wrapped with cloth, fur, wool, or steel wool; a plastic capsule or case that holds the cyanide; and a 7-cm ejector unit (VerCauteren et al. 2005a). The M-44 case is loaded with sodium cyanide and an additive to reduce caking. A spring-loaded plunger ejects the cyanide. When assembled, the components are encased in a tube driven into the ground. The cocked ejector with the case in the holder is screwed on top, placed into the tube, and baited with fetic meat, a lure, or tallow. When an animal is attracted to the bait and tries to pick up the baited case holder with its teeth, the cyanide is ejected into its mouth. Canids, skunks, raccoons, bears, and opossums sometimes are attracted to the bait used on M-44s; however, species specificity can be enhanced by proper site and lure selection (Acorn and Dorrance 1998). A study on coyotes in California found the M-44 was not a selective technique in targeting or removing the breeding animals involved in sheep depredations (Sacks et al. 1999a). The M-44 is registered and authorized by different agencies depending upon the country of use (e.g., Pest Control Products Act of Canada, Environmental Protection Agency) for control of coyotes, foxes, and feral dogs, and has numerous restrictions.

Aerial Hunting

Aerial hunting is commonly used for reducing predator numbers (e.g., Wagner and Conover 1999). Various fixed- and rotary-wing aircraft have been used in control programs for wolves, coyotes, bobcats, and foxes (Wade 1976). Hunting is most effective with snow cover because the target animals can be more readily spotted and tracked. When the specific animal is found, the pilot approaches at approximately 20 m of altitude, preferably into the wind. The ground speed of the aircraft is about 60–85 km/hour, but the air-speed should never approach the stall speed of the aircraft. A 12-gauge semiautomatic shotgun is the most common weapon used, with number 4 buckshot, BB, and number 2 shot preferred.

Several modifications have been made to fixed-wing airplanes to increase safety and effectiveness, including a larger propeller and drooped wingtips to provide added power, lift, stability, and maneuverability (VerCauteren et al. 2005a). Larger balloon-type tires have been added to provide clearance for the longer propeller and to better use primitive runways for landings. Rotary-wing aircraft (helicopters) also are used in predator control. The helicopter, with its ability to hover, can be more effective in rough, brushy terrain. Visibility and tracking ability are improved in models with a Plexiglas bubble cockpit.

Fixed-wing aircraft and helicopters can be used cooperatively. The helicopter is used for tracking and dispatching the animal, while the fixed-wing aircraft flies above the helicopter and maintains surveillance. This combination works in areas of thick vegetation or in areas where animals are hunted heavily with helicopters. Aerial hunting can be more

efficient if a ground crew works with the aircraft (Wade 1976). The ground crew induces coyotes to howl by using a horn, siren, voice, or recorded howl. When animals respond, the aircraft is directed to the area by 2-way radio communication. Early morning and late afternoon tend to be the most productive times for aerial hunting. Federal law requires each state where aerial hunting is allowed to issue aerial hunting permits. Some states also require low-level flying waivers.

Denning

Increased depredations of livestock (mainly sheep) and poultry during spring and summer by coyotes and foxes usually indicate that a pair of coyotes or foxes has a litter of pups nearby. During spring and summer, adults will increase their predation rates in order to provision pups (Till and Knowlton 1983). In a study in Wyoming, sheep losses to coyotes were greatly reduced after removal of only the pups, and was similar to reduction in predation rate when both pups and adults were removed (Till and Knowlton 1983). **Denning (direct removal)** of pups in the den, by digging or use of a chemical smoke cartridge, is often used to destroy the pups (Acorn and Dorrance 1998). An alternative to denning is surgical sterilization of adult breeding coyotes, which worked as effectively as denning, with a long term (several-yr) efficacy, but without the requirement of finding the den (Bromley and Gese 2001a, b).

Dens are usually located by tracking or observing the adults, or by use of simulated howling to get the pups to respond. Den hunting is often based on the assumption that adults that kill livestock will return to the den via the most direct route possible. An active den is evidenced by hairs around the entrance, fresh tracks, and (if the pups are large enough to have emerged from the den), matted and worn vegetation around the entrance and small scats. Dens also may have prey remains lying about the den area.

Den hunting is difficult and time-consuming, particularly on hard ground and in heavy cover (Acorn and Dorrance 1998). Some people use a dog to aid in locating the den. A call imitating a frightened or injured pup sometimes will bring adult coyotes near a den site, allowing the den to be located. Caution should be taken while digging out dens because of the possibility of cave-ins and ectoparasites. These hazards can be eliminated if a gas cartridge is used to kill the pups in the den. At times, an aircraft is used to locate coyote and fox dens. From the air, signs of an active den include cleaned-out holes and trampled vegetation.

Traps

Live traps (Fig. 34.20) of variable construction are available from several companies in various sizes and configurations to capture small, medium, and even large predators such as bears. Problem bears can be caught in a live trap made from steel culverts equipped with a trapdoor and trigger device,



Fig. 34.20. Live traps can be utilized to capture some predator species. Photo by U.S. Fish and Wildlife Service.

and mounted on a trailer that allows personnel to easily relocate the bear (VerCauteren et al. 2005a). Generally, coyotes, foxes, and bobcats are difficult to live-trap because of their cautious nature and reluctance to enter confined areas. However, a growing international concern for animal welfare is causing increased emphasis on more humane capture devices (Harris et al. 2006, Munoz-Igualada et al. 2008).

Canned dog or cat foods are effective **baits** to entice raccoons, opossums, skunks, and cats into live traps. Traps for skunks can be covered with a canvas or heavy cloth and provided with a flap for the door. When a skunk is captured, the trapper can approach the trap on the covered side and carefully drop the flap over the door, allowing the skunk to be transported to the release site. To release it, the trapper should stand beside the trap and ease the flap and door open; the trap may need to be propped open to allow the animal to leave when it is ready.

Foothold or steel traps are manufactured in various sizes. Modification of traps (e.g., padded jaws) and attachment of a trap **tranquilizer device** can greatly diminish injuries to the animal (Sahr and Knowlton 2000). **Tension devices** also should be considered to minimize captures of nontarget species (Phillips and Gruver 1996). Use of trap monitors (Benevides et al. 2008, Darrow and Shivik 2008) can be beneficial for traps or other capture devices set in areas with difficult access, or if trapping in areas occupied by endangered species that require prompt removal from the trap. Selectively removing (via trap) the offending animal causing the depredations can be difficult (Sacks et al. 1999a); however, sometimes just attempting to trap the offending animal and increasing the level of human activity in the area might deter future depredations (Harper et al. 2008). The following **trap sizes** are recommended for various species: numbers 0 and 1, for weasels and ground squirrels; numbers 1 and 1.5, for skunks, opossums, mink, feral cats, and muskrats; numbers 2 and 3, for foxes, raccoons, small feral dogs, nutria, marmots, and mountain beavers; numbers 3 and 4, for bobcats, coyotes, large feral dogs, badgers, and beavers; numbers 4 and 4.5, for wolves; and numbers 4.5 and 114, for mountain lions.

Success in trapping depends on placing the trap along travel ways, such as along dirt roads and trails. A trap usually is set in the ground by digging a shallow trench the size of the trap and deep enough to allow the stake (or drag) and chain to be placed in the bottom of the hole and covered with soil. The trap is set firmly on top of the buried chain and should be about 11 mm below the soil surface. A piece of canvas, cloth, mesh screen, or a plastic sandwich bag is placed over the pan to prevent soil from getting beneath the pan and preventing its depression. The trap is then covered with soil and other material natural to the area near the trap. The trap can be set without bait in a trail (i.e., a "blind" or trail set). Traps also may be set off the trail and baited with a lure, bait, or natural substance, such as scat or urine (a dirt-hole set). The trap is set in the same manner as the blind set, but instead of placing the scent on the ground, the lure is placed in a small hole (about 15 cm deep) dug behind the trap. **Lure selectivity** for the target species is important. The location of a set also influences its selectivity. When placed beside a carcass, a trap can catch nontarget animals such as vultures, eagles, badgers, and other nontarget predators. Many states no longer allow trapping near a carcass. Weather also can impact operation of traps, with frozen or wet ground preventing a trap from springing. Foothold traps must be checked often to minimize time captured animals are restrained. Most states have regulations on types of traps, baits, sets, and trap visitation schedules. Some states no longer allow use of foothold traps; state and local regulations should be consulted prior to conducting any trapping activity.

Calling and Shooting

Calling and shooting can be a selective means to control coyotes, bobcats, and foxes. Calling and shooting, with or without help of lure dogs, can be a means of removing offending coyotes that kill livestock, particularly during denning and pup-rearing seasons (Coolahan 1990, Sacks et al. 1999a). Several commercial calls and recorded calls are available from various manufacturers or outlets. The call is blown to imitate the sound of a rabbit in distress. This sound either arouses the predator's curiosity or indicates an easy meal. However, some predators become wise to calling. Conversely, the call may be an effective method to remove a trap-wise animal. Calls imitating a pup in distress also can attract the adults. Generally, 3 factors should be kept in mind to successfully call in a predator: (1) ensure the caller is downwind from the area being called to prevent the predator from detecting the caller's scent before the animal comes into shooting range; (2) within limits imposed by terrain and vegetation, acquire a full view of the area so the predator will be unable to approach unseen; and (3) avoid being seen by wearing camouflage clothing and hiding in vegetation (Acorn and Dorrance 1998). The most effective times to call predators are early morning and late afternoon. The hunter

can gain an added advantage by locating an animal before beginning to call by inducing howls. Calling at night and using a spotlight (where legal) also can be effective.

Hunting Dogs

Two types of dogs can be used for lethal predator control. Dogs that hunt by **sight** (i.e., greyhounds), can be kept in a box or cage until the predator is seen, then released to catch and kill the animal. This type of dog is effective only in relatively open terrain. The other type of dog is the **trail hound** (Fig. 34.21), which follows an animal by its scent. Trail hounds hunt on bare ground; however, snow or heavy dew makes trailing easier. Hot, dry weather makes trailing difficult; therefore, early morning is the most effective time to hunt with trail hounds. Bluetick, black and tan, Walker, and red-bone hounds, in packs of 2–5 dogs, are typically used. Trained trail hounds are used to catch and "tree" raccoons, opossums, bobcats, bears, and mountain lions. Often these dogs are able to track a depredating predator from a kill, making this method highly selective. State and local regulations should be consulted prior to hunting with dogs.

Snares

Snares are made of varying lengths and sizes of wire or cable looped through a locking device that allows the snare to tighten. There are generally 2 types of snares: body and foot. As described by Dolbeer et al. (1994b), the body snare is used primarily on coyotes and foxes. This snare is set where an animal crawls under a fence, at a den entrance, or in some other narrow passageway. The snare is situated so that the animal must put its head through the noose as it passes through the restricted area. When the snare is felt around the neck, the animal normally will thrust forward and tighten the noose.



Fig. 34.21. Trained hounds can be used to chase and tree some depredating predators, particularly mountain lions or black bears. Photo by U.S. Fish and Wildlife Service.

The **spring-activated** foot snare has been used to capture large predators (Logan et al. 1999). As described by Dolbeer et al. (1994b) when the animal steps on the trigger the spring is released, propelling the noose around the foot. The animal instinctively recoils, tightening the snare cable around the foot. The foot snare can be used in a bear pen or cubby set. A **bear pen** is just large enough to accommodate the bait, which is usually the remains of an animal killed earlier by the predator. The pen can be built of brush or poles and has an open end where the snare is set. The pen and guide sticks force the bear to step into the snare while trying to reach the bait. Bears and mountain lions also can be caught with a foot snare in a trail set (Logan et al. 1999). The snare should be set in a narrow trail known to be traveled by the animal. Deer and livestock can be prevented from interfering with the snare by placement of a pole or branch across the trail, directly over the set about 0.9 m above the ground.

Selectivity of the foot snare may be improved by placing, under the trigger, sticks that break only under the weight of heavier animals (VerCauteren et al. 2005a). Open-cell foam pads can be placed under trigger pans to prevent unintentional triggering of snares by small mammals (Logan et al. 1999). Foot snares have advantages over large bear traps in that they are lighter, easier to carry, and less dangerous to humans and nontarget animals.

SUMMARY

Wildlife-damage management can loosely be defined as resolving human-wildlife conflicts. Often, competition for limited resources between wildlife and society results in wildlife damage. Managers continually seek means to alleviate damage when wildlife threaten human health and safety (e.g., deer-vehicle collisions, zoonotic disease transmission), domesticated animals are damaged by wildlife (e.g., wolves preying on beef cattle), or resources are damaged (e.g., elk eating forage that was to be consumed by beef cattle).

Our world is continually changing, thus creating new challenges and compounding current challenges (i.e., urban sprawl, subdividing large landholdings, expanding populations of invasive species, climate change, and emerging infectious diseases) relating to the relationship between society and wildlife. As cities encroach into adjacent agricultural and undeveloped landscapes, highly adaptable species such

as Canada geese and white-tailed deer thrive in these new environments. These altered environments typically provide refugia (with minimal or no hunting pressure) to wildlife, which allows relatively unrestricted population growth, furthering potential for human-wildlife conflict. Increasing urban wildlife populations create unique management situations due to the attitudes and perceptions of urban stakeholders.

In this chapter, we introduced ways to assess wildlife damage, explored a diverse array of birds, ungulates, rodents and other small mammals, and carnivores and other mammalian predators commonly associated with damage, and we presented numerous management options that may be applied to reduce wildlife damage. Human-wildlife conflicts are growing and situations are becoming more varied; thus, techniques for managing these conflicts must be adaptable to be effective. Hence, we provided detailed information on a wide variety of proven tools and variations therein. The importance of approaching a management problem with an open mind must be emphasized, because each problem will likely deviate slightly from previous problems.

This chapter provides a starting point for laying out the framework (i.e., 4-part structure) for developing a wildlife-damage management program. Programs should be developed in steps, beginning with a definition of the problem and study of ecology of the problem species to understand why damage is occurring. This understanding should then be used to select and initiate appropriate management techniques, followed by an evaluation of the prescribed effort to assess efficacy and adapt the program if necessary. Further, an integrated approach utilizing several complimentary techniques is usually the best approach to reach a desired goal.

There appears to be a growing disconnect between society and wildlife management through lethal means, thus increasing the need for effective nonlethal tools. Yet incidents such as wildlife-related collisions with aircraft or vehicles will continue to be threats to human health and safety, due to potentially unmanaged wildlife populations. Furthermore, wildlife management professionals with expertise in public relations and formulating management plans will be fundamental in alleviating damage and ensuring management tools remain available for the future. It continues to be important that professionals in this field be well-versed in the human dimension aspects of human-wildlife conflicts.